EDEN: AN INTERACTIVE HOME NETWORK MANAGEMENT SYSTEM

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EDEN: AN INTERACTIVE HOME NETWORK MANAGEMENT SYSTEM

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HCI	Human Computer Interaction
GUI	Graphical User Interface
URL	Uniform Resource Locator
HTTP	Hypertext Transfer Protocol

SUMMARY

Networks have expanded from the workplace and scientific labs into the home. Consequently, managing networks is no longer only a job for skilled network administrators, but has also become one for general home users, who have to deal with various home network management tasks such as network/device configuration, security management, and troubleshooting to name but a few. However, many home network users have difficulty managing these tasks due to the inherent complexity of the home network and the lack of management tools designed for non-skilled network users.

This dissertation addresses the problem of network management for non-skilled network users by investigating a home network management tool with a new interaction model called Eden.

Eden is an interactive home network management tool based on direct manipulation. It eliminates the need for users to see all the technical minutia of the network while still allowing users to perform management tasks with a simple drag-and-drop of visually represented networking devices and network settings. The user interface evaluation showed that Eden is intuitive and easy enough for general home users to use. The usability evaluation showed that Eden performed better overall than existing tools and that the majority of the study participants preferred Eden over the existing tools for future use.

My contributions are twofold. First, I present what is to my knowledge the first fully direct manipulation system designed specifically for home network management. Secondly, my evaluation highlights a number of properties in my design—particularly in

my conceptual model—that improve users' understandings of the network, and their ease with managing it.

CHAPTER 1

INTRODUCTION

1.1 Usability Problem of Home Network Management

Since the broadband Internet was first adopted in homes in the late 90's, the home network has become an essential part of everyday home computer use. Through their home networks, people visit websites, send emails, share files and photos, communicate with other people, and find more uses every day. Further, the ubiquitous "smart home" – a domestic environment in which various types of networked computing devices are interconnected to provide intelligent services - will make the home network an even more deeply integral part of people's lives.

As the home network has become a normal part of people's daily lives, network management has become a regular task of the household (Tolmie et al. 2007). Home network users - whether they want to or not - have to deal with various home network management tasks. They need to configure network devices for connectivity, do access control in order to protect their home networks from unwanted access, assert parental control for safer Internet use by their children, and diagnose connectivity problems to name but a few. Managing the network is no longer only a job for skilled network administrators, but has also become one for general home users (Chetty et al. 2007).

However, many home network users have difficulty doing such management jobs (Bly et al. 2006; Franzke and McClard 1996; Kiesler et al. 2000; Edwards and Grinter 2001; Grinter and Edwards 2005; Shehan and Edwards 2007). The primary reason for such difficulty is that the home networking technology itself is a complicated infrastructure technology. Managing the home network involves not just the physical aspects of management such as cabling and connecting but also digital aspects such as

configuring IP and security parameters - which are effectively invisible without the use of a corresponding application (i.e. a management tool) that allows these to be visible and more easily controlled.

Such inherent complexity of the home network makes the role of a network management tool critical in Human Network Interaction. Since a network management tool determines what management tasks are supported and what networking knowledge is required for users to perform the tasks, how it supports user task management significantly affects the quality of Human Network Interaction.

While there are a variety of powerful tools for network management, they usually make a poor fit for general home network users, most of whom have neither sophisticated technical knowledge nor motivation to learn complex tools (Chetty et al. 2007; Edwards and Grinter 2001). Currently available tools are typically very technical in nature and designed for skilled users, who should have technical knowledge of the operational concept of the home network, the components of the home network, and networking terminology. For instance, just to add a new client device to the home network, users must understand the basic network architecture of the home network (that a router is the core device making up one unit of the home network and bridging the internal to the external), IP technology (IP addresses, DHCP, DNS), wireless network and security technology (SSID, encryption), and more. Users have to know all these technologies; otherwise, they will not be able to add a new client device to the home network.

In my dissertation, I address the problem of network management for unskilled users by investigating a home network management tool based on direct manipulation (Shneiderman 1983), which could allow unskilled users to achieve their management goals just by simply dragging and dropping graphical network objects without the users having to worry about low-level networking minutia.

1.2 Research Initiative

The initial idea for my research came from prior research reporting the utility of a visual home network diagram (Tolmie et al. 2007). According to the study, a visual diagram of a home network, even a very simple one with only the physical components (i.e. networking devices) depicted, tended to help users understand the conceptual and operational models of their home networks.

This led me to further investigate the visual diagram of the home network for network management:

- to visually present the home network of a user with all users' actual (existing) networking devices depicted
- to convert the users' actual (existing) networking devices into interactive objects on which users can directly perform tasks on those visually represented objects
- to make invisible digital controls correspond to management tasks as visual interactive objects so that users can apply digital controls to the networking devices.

For instance, a user blocks the child's computer from accessing the Internet by clicking on the child's device on the screen instead of doing some firewall rule composition or any other manual configurations, as is necessary with a traditional text-based network management tool.

This idea led me to apply direct manipulation to the domain of home network management.

1.3 Direct Manipulation and Home Network

Direct manipulation is an interaction model that allows users to directly manipulate objects of interest and immediately see the results of the manipulation. Shneiderman (1983) defined the three properties of direct manipulation:

1. Continuous representation of objects of interest
2. Physical actions or labeled button presses instead of complex syntax
3. Rapid, incremental, reversible operations whose impact on the object of interest is immediately visible

The continuous graphical representation of objects based on a model-world metaphor provides users with an awareness of the components of the system and helps them understand the system using their analogical power often formed from a real world metaphor familiar to them.

As opposed to the application of complex syntax, physical actions such as movement and labeled button presses reduce the cognitive complexity of mapping psychological variables of interest by providing simple and straightforward translation between goals and actions. Consequently, users should make fewer errors while performing tasks more effectively and efficiently.

Finally, rapid, incremental, reversible operations whose impact on the object of interest is immediately visible allow users to see the system output in a form readily interpreted in terms of the goals of interest to the user. Since users can see the results of their actions immediately, they can determine whether their actions improve or hamper their goals. Reversible actions allow errors to be easily corrected. They also encourage users to explore system features without worrying about making changes that will "break" something. Lastly, predictable and immediate responses give users more confidence and mastery of the system.

I expect that the properties of direct manipulation can make home networks easier to manage in the following ways. First, these properties will make clear to the home user exactly which components are parts of the home network and what the relationship is between any two components. The home network consists of multiple physical and digital components. Without knowing which components exist and how to control them, users will have difficulty achieving their goals. For instance, let us say that parents want to prevent their children from accessing the Internet. To do this, parents first have to know which home network component is responsible for controlling Internet access and how to control the component. I believe, by representing physical or digital components associated with management tasks as continuous graphical objects, we can increase the home user's awareness of the components and the ways in which he can control them.

Another advantage of converting physical and digital components into graphical objects is that this can hide backend networking minutia associated with these components behind graphical objects so that users do not need to concern themselves with the backend networking syntax. Instead, home users simply focus on the tasks they need to perform on the graphical objects. For instance, if users want to add a new device to the home network, they just drag the device icon into some region spatially associated with the home network. If users want to add an Internet access control to a certain device in the home network for parental control, they can put a graphical object representing Internet access control onto the device instead of doing some manual configuration with firewall software.

Finally, immediate visual feedback helps the home user evaluate the system output and decide if he furthered or hampered his goal. In addition, easy reversible operations of direct manipulation can reduce the anxiety of the user regarding errors that he can make. During the user evaluation sessions in my former project, ICEBox (Yang and Edwards 2007), many novice users were observed hesitating to take actions within

their home network due to their fear of possibly breaking something as a result of their actions.

The primary benefits of direct manipulation include learnability and efficiency (Shneiderman 1982). Novice users can easily learn and use the system, and knowledgeable users can perform tasks more efficiently.

Since its introduction, direct manipulation has been applied in many distinctive systems, including XEROX STAR (Smith et al. 1982), APPLE Macintosh (Williams 1984), and many applications such as drawing tools, word processors, and spreadsheets. These successful systems empirically demonstrated the benefits of direct manipulation.

In my dissertation, I aim to bring the benefits of direct manipulation to the domain of home network management, especially for unskilled users with little technical knowledge of networking. I expect that by representing the home network in a certain visible form and adding straightforward actions with corresponding feedback to the visual form of the home network, I expect to make home network management simpler and easier for the home user.

As Hutchins, Holland, and Norman (Hutchins et al. 1985) argue, there are two basic ways to reduce the distance between a goal and the actions to achieve the goal. One way to limit the distance is from the system side, which requires effort on the part of the system designer. The other way is from the user side, which requires effort on the part of the user. In the former approach, the designer constructs higher-level and specialized languages that move toward the user, making the semantics of the input and output languages match those semantics of the user languages. In the latter approach, the user develops competence by building new mental structures to bridge the gulfs, which requires the user to learn to think in the system's language.

As of yet, most tools go about network management from the latter approach, which makes it difficult for unskilled users to manage their home network. In my work, I argue for the former approach.

1.4 Research Statement and Questions

In my dissertation, I present the following thesis statement:

> "A home network management system based on direct manipulation can simplify home network management and thus increase the usability of the home network for users who have either only informal or no technical knowledge of networking"

The dissertation examines the following research questions:

Q1. What visual representation and task activation paradigm would be effective for users who have either only informal or no technical knowledge of networking?

Q2. Does a new interaction model based on direct manipulation enrich users with no technical knowledge of networking and help them begin to understand the conceptual model and functions of the home network so that they can carry out basic management?

Q3. Does a new interaction model based on direct manipulation help users with informal knowledge of networking understand the conceptual model and functions of the home network and better perform tasks in terms of effectiveness and efficiency, compared to the network management tools they have used in the past?

Question 1 is intended to address the two key factors in the success of designing a direct manipulation home networking management system - how to visually represent the home network as an interactive model-world

environment and how to design task activation paradigms in that environment (Shneiderman 1983; Frohlich 1996).

Questions 2 and 3 articulate the hypotheses in the thesis statement and serve as the ultimate evaluation metric for experiments to evaluate the proposed network management system. Answering these questions will validate or invalidate the thesis statement.

1.5 Research Methodology

While designing a home network system based on direct manipulation, I took an iterative user-centered design approach as shown in Figure 1.

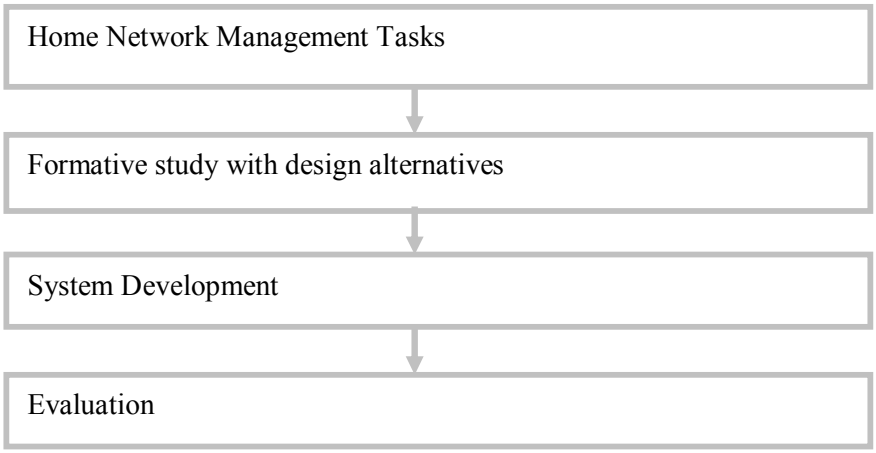

Figure 1: The system development process

I first defined a set of home network management tasks. In defining the tasks, I first made a list of basic home network management tasks. To make this list, I included the basic home network management tasks that are currently performed by using general routers, operating systems, and existing home network management tools. I also tried to include the users' needs and desires which were revealed in my formative study (e.g.

network monitoring for the whole home network and user-driven QoS management for bandwidth usage).

Then I designed design alternatives for visual representations of the home network and task activation paradigms. With the design alternatives, I conducted a formative study with 14 users in order to figure out the visual representation and task activation paradigm that best fit the users, especially the users with little knowledge of networking. Since there were no reported studies on the tools that users currently rely on to manage their home networks, in the formative study, I also collected data on current network management tools and any usability problems with those tools. The results and findings of the formative study informed the final system.

Based on the formative study results, I developed the final system and then conducted the evaluation of the system, which consisted of two sub sessions: 1) a qualitative user interface study of the system and 2) a usability study of the system, comparing it with existing management tools.

1.6 Dissertation Outline

In Chapter 2, I review existing network management tools and then present empirical studies revealing the usability problems of home network management and a few tools to address the problems.

In Chapter 3, I discuss the context setting in which I work. I discuss the 5 home network management tasks categories that I deal with in this work, the role of the management system and the user in home network management, the limitations and caveats of my work, and the target users of the system.

In Chapter 4, I describe both the design alternatives for the visual representation of the home network and task activation paradigms as well as the formative study methodologies and results.

In Chapter 5, I discuss the user interface of the final system, focusing on its user interface metaphors embedded in the visual representation and task activation paradigms. Before getting into the user intreface of the final system, however, I first summarize the theatrical background of the role of metaphor in human cognition in order to clarify the role of the metaphors in the user interface. I then discuss the details of the user interface metaphors and the user interaction features of Eden with the presentations of how users can perform management tasks with Eden.

In Chapter 6, I discuss the implemetaion details of Eden, including the development platform and embodiment, implementation architecture, and details.

In Chapter 7, I present the evaluation procedure and results of the proposed system.

In Chapter 8, I conclude the dissertation a summary of my work and suggestions for future work.

CHAPTER 2

RELATED WORK

This chapter first reviews traditional network management tools. It then presents empirical studies that report home network management usability problems and some tools that have addressed these problems. The chapter then presents how my system is different from existing network management tools.

2.1 Traditional Network Management Standards and Tools

Network management has a long history in the network community. With tremendous growth in network deployment in the 1980s and 1990s, network management became an important issue. As networks grew in size and complexity, efficient network configuration and management became crucial for their success.

Consequently, international standardization bodies and organizations began to introduce many network management specifications regarding the operation of large networks. Among the well-known standards are IETF's Simple Network Management Protocol (SNMP) (Rose 1996) and Netconf [1], and OSI's Common Management Information Service (CMIS) (ISO DIS 9595) coupled with Common Management Information Protocol (CMIP) (ISO DIS 9596).

IETF's SNMP, the most widely-used protocol, was designed to help manage network devices in the growing Internet and other attached networks. SNMP is an application layer protocol, which is built on top of the Transmission Control Protocol/Internet Protocol (TCP/IP) protocol suite. It basically facilitates the exchange of

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[1] http://www.ietf.org/html.charters/netconf-charter.html

management information between network devices. The basic SNMP architectural model consists of three components – managed devices, agents, and network management stations. A managed device is a network node that contains an SNMP agent, which collects and stores management information and makes this information available to network management stations. Managed devices can be any network nodes, including routers and access servers, switches and bridges, hubs, computer hosts, or printers. SNMP enables network administrators to manage network performance, diagnose network problems, and plan for network growth.

Netconf of IETF's Network Configuration Working Group, provides a standard framework and a set of standard Remote Procedure Call (RPC) methods to install, manipulate, and delete the configuration of network devices. Netconf was designed to make up for the shortcomings of SNMP for device configurations.

OSI's CMIS/CMIP provides a specification for the monitoring and controlling of heterogeneous networks. Like SNMP, CMIS/CMIP facilitates the exchange of information and commands between network devices for management purposes.

In addition to the standards mentioned above, there are many other network standards, including Telecommunications Management Network (TMN) (Sahin et al. 1998) of ITU-T, Enterprise Management Forum[2] of Open Group, among others. As the standards mentioned above, all these standards also focus on how to efficiently manage large scale networks such as enterprise-class networks.

Based on these standards, many proprietary network management suites for organization-wide network management were introduced, including NetView (Ahmadi 1998) of IBM and OpenView (Muller 1996) of HP.

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[2] http://www.opengroup.org/management

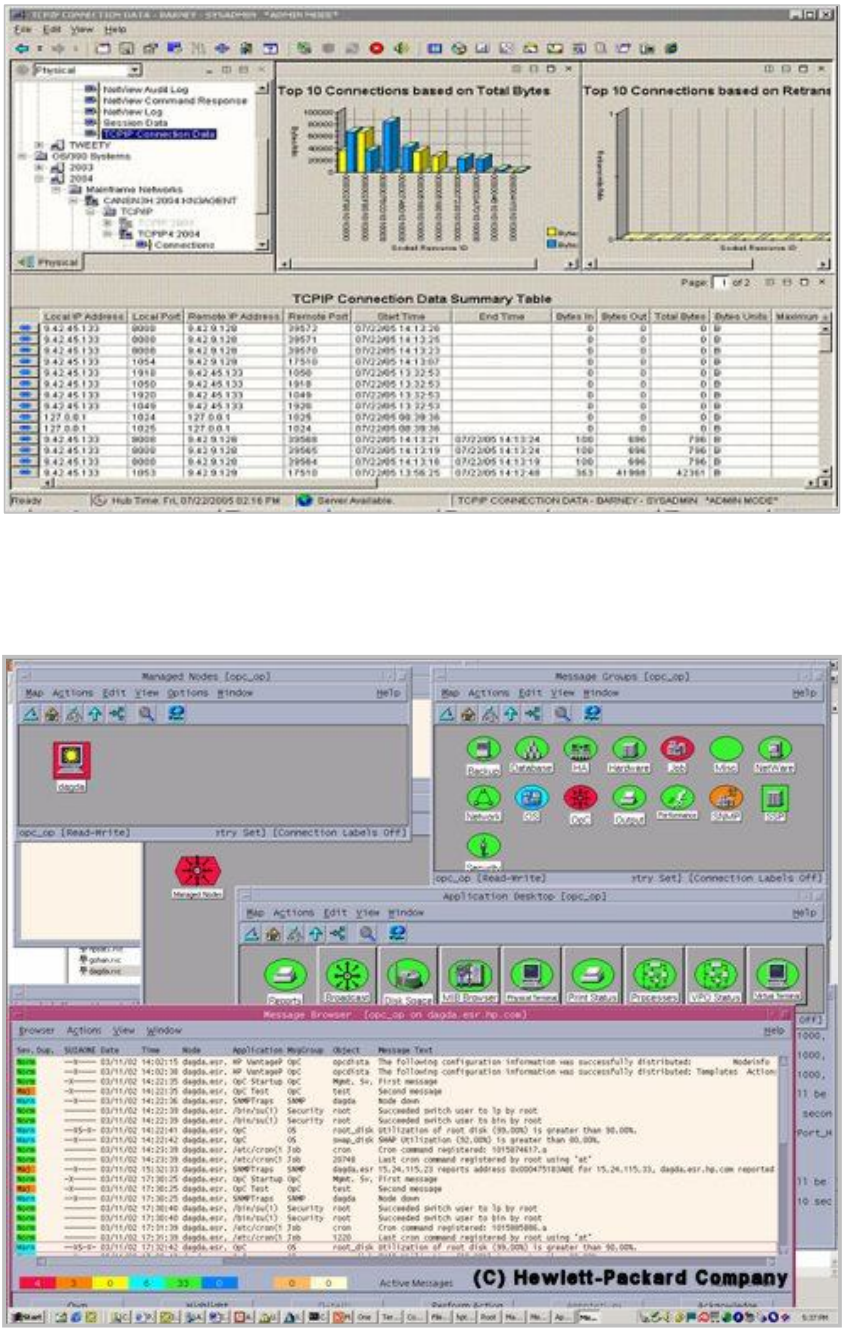

Figure 2: IBM's NetView (top) and HP's OpenView (bottom)

NetView is a scalable distributed network management solution for enterprise-class networks. Based on SNMP, it provides comprehensive management functions for large-scale networks. NetView discovers TCP/IP networks, displays network topologies, correlates and manages events and SNMP traps, monitors network health, and gathers performance data. NetView helps with the management of large networks by providing scalability.

Similary, OpenView is a management suite designed to facilitate large-scale system and network management of an organization's networks. Like NetView, it helps network administrators with application management, device availability, network conditions and status, system performance, and service and program maintenance.

Along with complex management suites for large scale networks, a number of network management tools[3] have been introduced for a variety of management aspects. For instance, network traffic analyzers help with IP traffic analysis. These tools (also called network sniffers, packet sniffers, or IP sniffers) capture all incoming and outgoing packets passing through the network and sort them according to host names, port numbers and transmission protocol. Then they provide comprehensive visualized reports and charts to help users analyze network behaviors such as network usage and performance problems. There are numerous proprietary and free traffic analyzers, among them, Cisco's NetFlow[4], GNU's ntop[5], Ethereal[6], and PacketTrap[7].

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[3] http://www.slac.stanford.edu/xorg/nmtf/nmtf-tools.html
[4] http://www.cisco.com/en/US/products/ps6601/products_ios_protocol_group_home.html
[5] http://www.ntop.org
[6] http://www.ethereal.com
[7] http://www.packettrap.com

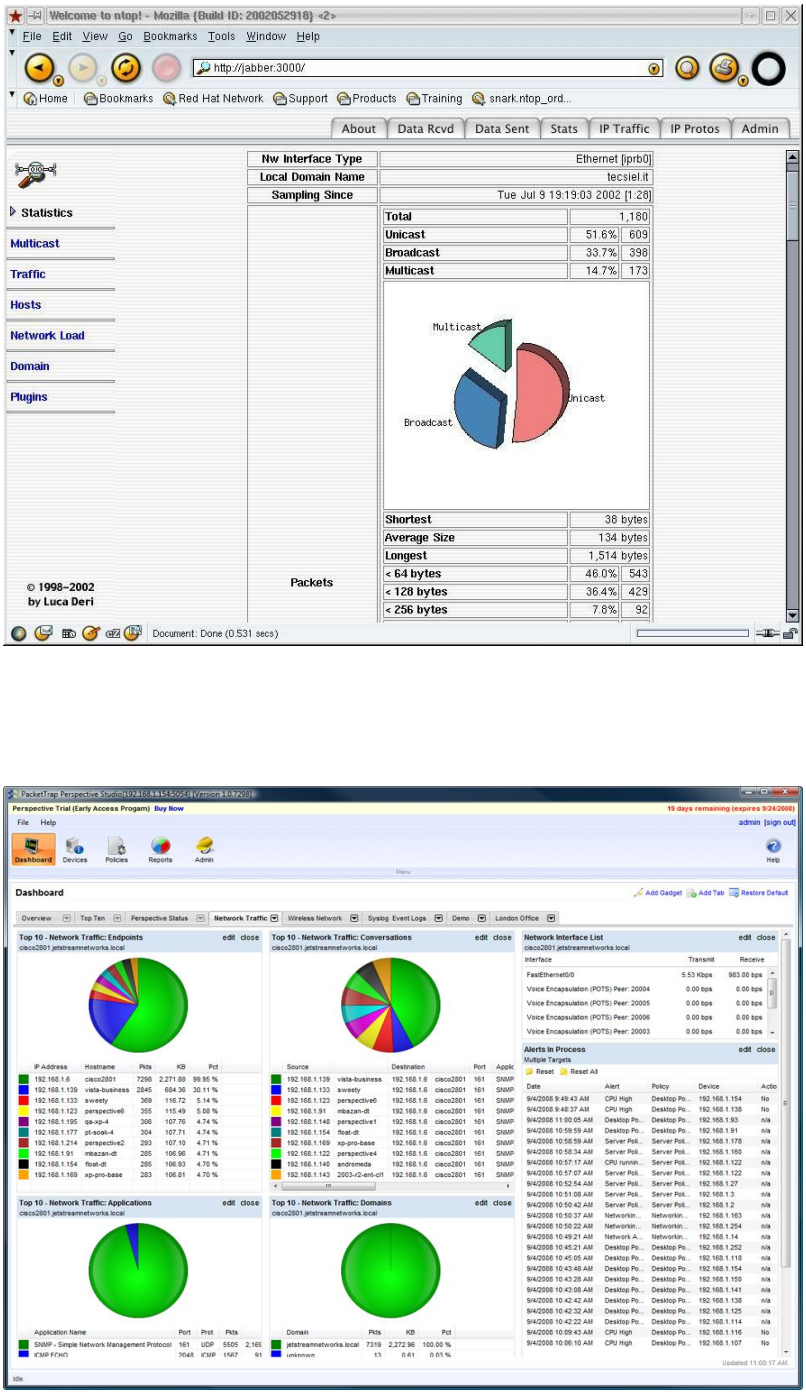

Figure 3: GNU's ntop (top) and PacketTrap (bottom)

There are also tools that focus on visualizing large scale networks with a large number of network nodes (Abello et al. 1999). For instance, CAIDA's Mapnet[8] visualizes the infrastructure of multiple international backbone providers. It draws the geographical locations of backbone providers on a map of the world. CAIDA's Walrus[9] provides interactive large directed network graphs in a 3D space based on visualization techniques such as fisheye and context-focus. These tools usually adopt various visualization techniques such as fisheye or hyperbolic views to effectively visualize large number of network nodes. There are tools that visualize Internet routing protocol data such as Border Gateway Protocol (BGP) in order to help network managers characterize the behavior and topology of routing and detecting anomalous events in large networks (Au et al. 2004; Teoh et al. 2002).

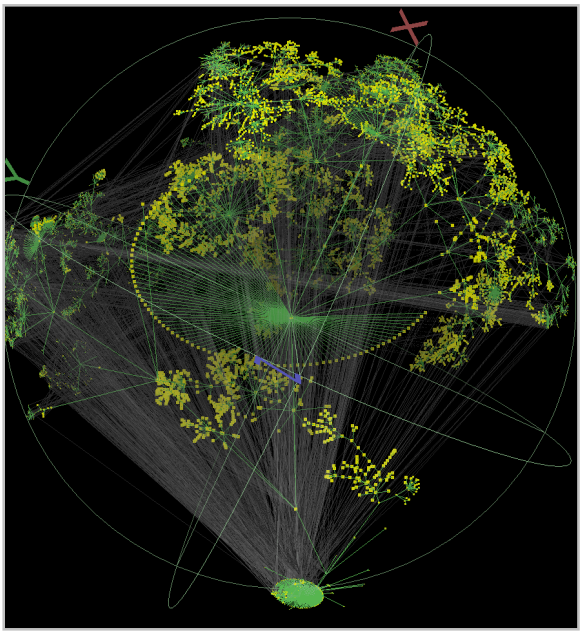

Figure 4: CAIDA's Walrus – visualizing network topology graphs

[8] http://www.caida.org/tools/visualization/mapnet

In addition to network visualization tools which visualize such basic network topologies, there are many network visualization tools that support other aspects of network management. One prominent branch of them is network visualization tools that support network intrusion detection (Ball et al. 2004; Papadopoulo et al. 2004; Teoh et al. 2002). These tools help users detect network intrusions by providing the comprehensive analysis of network traffic patterns with an interactive graphical user interface based on various interaction techniques such as filtering and timelines. The Honeynet project [10] also focuses on detecting client-side computer attacks.

For wireless networks, there are also network intrusion detecting tools. One is Interactive Visualization of Wormholes (IVoW) (Wang and Lu 2007), which uses an automatic detection algorithm to help detect intrusion in large-scale wireless networks in real time. It adopts various visual forms to assist in the understanding and analysis of wireless network topology and to improve detection accuracy.

There are also diagnostic tools that help check the availability, reachability, and health of the network or the host in a network using ICMP and SNMP. Among them, the most primitive diagnostic tools include "ping", "traceroute", "DNS resolver", "BGP route", and so on. These tools are either used stand-alone or integrated into complex network management suites such as those described in previous sections.

2.2 Why Not Traditional Tools for Home Network

The existing management suites and tools discussed in Section 2.1 are not appropriate for the household. First, those suites and tools are designed for large-scale networks such as enterprise-class networks, which consist of a number of sub networks and hosts. Consequently, the management concerns of those tools focus on effective

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[9] http://www.caida.org/tools/visualization/warlrus
[10] http://www.honeynet.org/

management of large-scale networks such as account management, organization sever configuration, and complex network diagnosis. Unlike these large enterprise-wide networks, the home network is usually much smaller with different management concerns. Most importantly, the home has not access to professional managers who can learn and use these complex tools.

Second, they were originally designed for use by skilled network administrators. They require the user to have a working knowledge of low-level networking concepts such as network protocols and packets that are unfamiliar to general home users. Therefore, to use these tools, home users would have to have the same degree of networking knoweldge, which is unrealistic. Combined, the difference in system focus and the difference in required user training makes these suites and tools inapproproate for most unskilled home users who want to manage their relatively small home network.

2.3 Empirical Studies on the Usability Problem of Home Network

As home users have become more and more responsible for managing their home networks, researchers have taken notice.

A number of users were found to run into difficulties as they try to build and manage their home network (Bly et al. 2006; Franzke and McClard 1996; Kiesler et al. 2000; Edwards and Grinter 2001; Grinter and Edwards 2005; Shehan and Edwards 2007). According to Kiesler et al (2000), over 70% of home users needed technical support to set up their computer and connect it to the Internet for the first time, and 90% of the households called the help desk for technical support during the 1st year of Internet usage. Furthermore, many inexperienced home users do not call the help desk, especially if they feel they do not have the necessary vocabulary or background knowledge to discuss an issue with a technical person.

The inherent complexity of networks has made home networking a formidable task for even the most technically advanced people – those with advanced degrees in

computer science – as well as general home users (Grinter and Edwards 2005, Chetty, Sung et al 2007).

Along with its complexity, the invisiblity of the home network makes home network management even more difficult (Grinter et al. 2005). Home users with inadequate networking skills often omit the most important network components such as routers and broadband network modems when they are asked to sketch their home networks (Shehan et al. 2008). This is because both the physical invisibility of the home network (e.g. hiding networking gears behind furniture for aesthetic reasons) and the digital invisibility of the home network (e.g. device relationships, protocols, and configurations, etc).

Such invisibility gives users an incomplete view of the home network, which consequently makes management of it difficult. This reminds us of the importance of the visibility of the home network components. If users are to manage their home networks successfully, they should be given an accurate, complete conceptual model of their home. Researchers agree that one of the best ways to make a network more "visible" to the home user is by presenting it as a diagram (Tolmie et al. 2007).

Because of the usability problems of home network management, researchers have called for network management tools for general home network users (Chetty et al. 2007; Edwards 2001). They suggested more interactive tool for home network users who have neither the sophisticated technical knowledge nor the motivation to learn complex management systems currently designed for network administrators.

2.4 Technologies and Tools that Address the Usability Problem

There are a number of technologies to improve the usability of network management by removing manual configurations for some aspects of management. For instance, the Dynamic Host Configuration Protocol (DHCP) (Droms 1997) removes the chore of manually configuring certain low-level network parameters such as IP addresses,

DNS servers, gateway IP addresses, and subnet masks for each device on the network. Other such technologies include discovery protocols such as the Simple Service Discovery Protocol (SSDP) used by UPnP (Jeronimo and Weast 2003) and Zeroconf (Cheshire and Steinberg 2005). These systems provide peer-to-peer announcements and naming services that allow clients to discover services on the network. These technologies share a similar focus: reducing the complexity of configuration. Similarly, Cisco's Home Network Administration Protocol (HNAP) (Cisco 2009), an HTTP-SOAP based discovery and management protocol, allows remote devices to configure and manage other devices (e.g. network routers, cameras, and small devices, which do not have UI themselves). Using HNAP, manufacturers can display custom, device-specific information and tasks in applications that use HNAP for device discovery and management.

In addition to these technologies, research from the networking community has introduced new technologies and tools to improve the usability of home networking. PARC's Network-in-abox (NiaB) system (Balfanz et al. 2004) allows users to add computing devices to a secure wireless network by walking up to an access point and physically pointing a laptop at it. NiaB uses a short-range communication mechanism to facilitate the exchange of certificates needed for 802.1x wireless security.

Windows Connect Now (WCN) (Microsoft Corp. 2005) is another technology that provides an alternative mechanism for home wireless configuration in which users run a Wireless Network Setup Wizard that configures their computer for a new wireless network and saves the configuration details on a USB key. Users then take the USB key and insert it into the USB port of the wireless access point to update its settings. To add another computer to the wireless network, users simply insert the USB into it and run the Wireless Network Setup wizard again on that computer. While WCN clearly simplifies the process of setting up a wireless network, it deals only with basic SSID and WEP key

provisioning for wireless networks. A further drawback is that it requires significant interaction (running the Wireless Network Setup Wizard) at each device.

My previous work, ICEbox (Yang and Edwards 2007), also address the usabiltiy problem of device provisioning. However, ICEbox deals primarily with broader aspects of device provisioning, including lower-layer configuration details (such as link layer or physical layer configuration, including WiFi provisioning), trust associations (such as WEP keys, 802.1x certificates), or higher-layer application defaults (such as printers or file shares).

All the above technologies and tools, however, only partially address the usability problem of network management. They do not, for instance, address access control for home network data and Internet, network monitoring, or network diagnosing.

Recently, Cisco introduced a home network management solution, Network Magic[11] (Figure 5), to address the usability problem of home network management. Network Magic is the work most closely related to mine. Its intended purpose is to empower users by freeing them from the hassles of technology.

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[11] http://purenetworks.com/

(a) Management task panel (b) A visual tree map of devices

(c) Help/Advice panel (d) Access control

Figure 5: Cisco's Network Magic

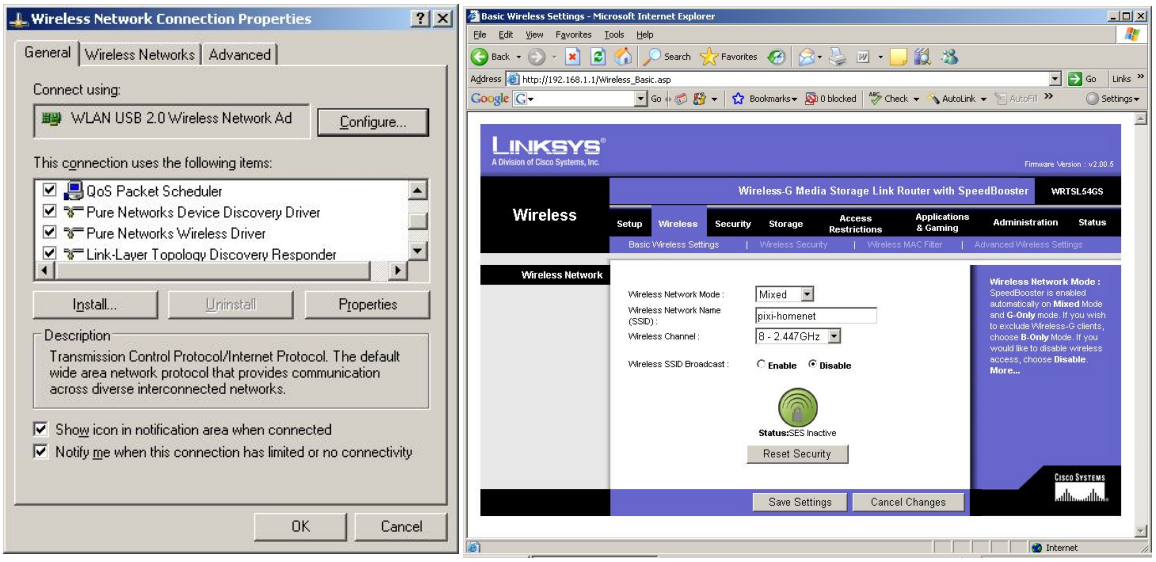
Network Magic provides a comprehensive set of household-oriented tasks including device configuration, wireless security, network speed, network status monitoring, folder sharing, troubleshooting, and network advising with a much more user-friendly user interface. It also provides a much more user-friendly view, (a visual tree map of devices on the home network) compared to the existing management tools described above.

The user interaction model of Network Magic is, however, not much different from those of existing management tools. Although it provides a visual representation for some part of the home network components, it does not fully support the interaction features of direct manipulation. Network Magic provides visual representations for only a subset of home network components – at most, a router and individual computing devices. What users can do with those devices is change a device name or an icon type and see the configuration and status information of the device, including its name, connectivity status, IP address, subnet mask, MAC address, operation system, and connection speed. However, for these devices, management tasks including configuration, security, and status monitoring must be done on separate task panels through menu- and dialog-based user interactions. In other words, objects and actions are not closely coupled with each other. Furthermore, it still requires users to have some technical knowledge of networking to use it. For instance, users need to manually build and maintain a secure wireless home network just as they need to do with traditional network management tools. They first need to make a wireless home network secure by using the wireless security technology and then add a device to the secure wireless home network through the wireless security technology.

2.5 Tools Built-into Networking Gear and OS

My formative study and my system's evaluation study indicated that tools built-into networking gear such as the router and OS are the tools that home users most rely on to manage their home network.

These tools, however, directly expose end users to all networking minutia, including the concept of the MAC address, the IP address, the port number, the TCP/IP, the UDP, SSID broadcasting, port forwarding, DHCP server/client, just to name a few. To perform network management tasks with these tools, users need to understand all the networking terminology and have a decent amount of prior knowledge of networking. Otherwise, they won't be able to accomplish management tasks with these tools.



(a) Network configuration wizard built into Windows OS

(b) Network management tool built into a router

Figure 6: Tools built-into OS and a router

2.6 Research Tools for System and Network Management

There is some work in other infrastructure management domains that utilizes highly interactive visual objects of direct manipulation. For instance, Jigsaw (Humble et al. 2003) used graphical objects in the form of "jigsaw pieces" to support dynamic composition of ubiquitous home components. Harrop and Armitage's (2006) 3D first shooter game was used for IP network monitoring and network intrusion detection. Such systems try to reduce the complexity of previous command line tools. In (Chao 2001), psDoom was used to help less technical users manage operating system resources. The system took on the familiarity and metaphor of a user interface of a game, Doom, to create an intuitve user interface for process management to help less technical users manage processes.

2.7 My Novelty

To the best of my knowledge, Eden is the first trial that utilizes highly interactive visual objects of direct manipulation in home network management. The novel aspects of Eden include the following:

1. Eden provides a task-oriented GUI in user-friendly terms while hiding all underlying technical networking minutia.
2. Eden represents networking devices as visual interactive objects on which users can directly perform tasks with simple physical manipulation of the visual objects.
3. Eden makes invisible digital controls correspond to management tasks as visual, interactive objects so that users can apply digital controls to the networking devices represented by the visual objects.

CHAPTER 3

HOME NETWORK CONTEXT SETTING

This chapter describes the context setting for the current research. In Section 3.1, I describe the home network management categories and tasks that Eden, my system, deals with. In Section 3.2, I discuss the role of Eden and the user in home network management. In Section 3.3, I discuss the limitations and caveats of my work. Finally, Section 3.4 details the target users of my work.

3.1 Network Management Categories and Tasks

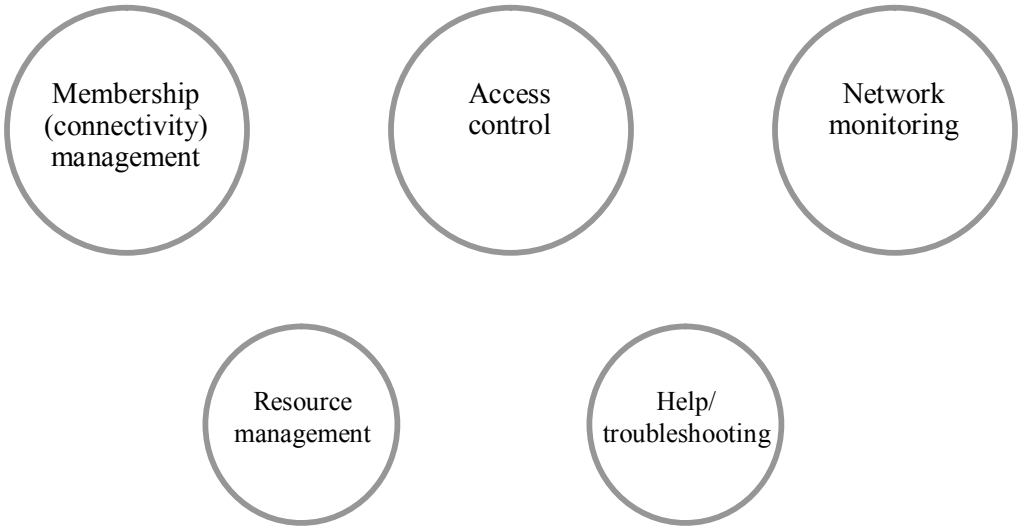


Figure 7: Management task categories

I categorize home network management work into five areas. The first two, membership management (adding or removing a device to or from the home network) and access control (controlling access rights to the local network and the Internet

resources in order to block or allow accesses to those resources), are fundamental parts of home network management in that they are the first step to building the home network. The third area is network monitoring, which makes users aware of the current behavior and health of their home network. The fourth area, resource management, allows users to allocate network resources, e.g., network bandwidth. The fifth area, help and troubleshooting, is an assistive part of home network management. The user scenarios corresponding to the management categories will be discussed in the sub-sections in which each category is discussed in detail.

To get to the five network management categories outlined above, I first made a list of basic home network management tasks. I included most home network management tasks that can be performed by using general routers, operating systems, and existing home network management tools. I also included the users' needs that were revealed in my formative study (e.g. network monitoring for the whole home network) and some potential tasks (e.g. resource management).

I then categorized these tasks according to their role in home network management by referring to a well-known network management model, the ISO Network Management Model (NMM), which addresses the five major functional areas of enterprise network management: configuration management, security management, performance management, accounting management, and fault management. I then slightly modified the way that the ISO NMM categorizes network management tasks in order to fit the context of home network management. For instance, I removed accounting management, which deals with billing based network usage, since it has nothing to do with the context of the home network. I also renamed the categories so that the categories are more residential user task-oriented rather than technology-oriented. For instance, I renamed configuration management, which deals with home network membership, as membership management. I renamed security management, which deals

with controlling access to home network resources, as access control. In the rest of the section, I discuss each category in detail with the tasks that Eden supports.

3.1.1 Membership Management

Membership management is the most fundamental part of home network management. Home network users need to decide the membership status of each client device in their home network.

My research includes both wired (network cables) and wireless networks (802.11 wireless technologies), which are currently the two most common transmission technologies. My research also supposes the Internet Protocol (IP) technology as the base of home networking. Thus membership management, at a minimum, involves dealing with these transmission technologies and the IP technology.

Membership management consists of two basic operations – adding client devices to the home network and removing client devices from it. With the current home network setting, adding client devices requires users to physically attach client devices (either wired or wireless) to the home network and configure the client devices with the IP parameters of the local home network so that each device becomes a member of the home network. If users add any client devices, wired or wireless, they need to configure these with the IP parameters either manually or automatically by using auto-IP configuration tools such as the DHCP technology. Any wired client devices then become members of the home network. For wireless client devices, users additionally need to configure link-layer settings including SSID, WEP/WPA keys, and more. This configuring is designed to prevent any anonymous (unwanted) wireless client devices from becoming a member of the home network.

With the current home network setting, removing client devices from the home network also requires configurations at the router. If users tell the router to block DHCP services based on the MAC addresses of client devices, something called MAC filtering,

they can reclaim the IP parameters assigned to the client devices and prevent their devices from being assigned IP parameters.

In my work, I provide ways for users to easily add or remove client devices. I take away the users' need to configure all manual networks, wired or wireless. I also eliminate the need for the users to understand the wireless security technology to configure its parameters at both the router and client devices. Furthermore, I get rid of all manual work for device removal. Therefore, all users ultimately need to do for membership management is to express their membership decisions on the GUI.

3.1.2 Access control

The second basic operation of home management is preventing the unauthorized access of home network resources such as devices, data, and applications. The home network allows internal devices to share resources. It also allows external devices to remotely access its resources. Optimum access control should appropriately block or allow internal or external access to the devices and resources of the home network.

There are many situations in which users need to control access, often to block or allow access requests from internal and external devices. For instance, they may want to run a web server at their home and allow incoming HTTP requests to come in to the web server. They may want to allow a specific set of external devices (e.g. devices of family members) outside the home to remotely access a media server on the home network. Parents may want to monitor and control their children's outgoing requests for the Internet or online game access (Poole et al. 2008).

Users may wish to block a group of client devices on the home network from having access to other devices or data on the local newtork. For instance, if users have a visitor at their home, they might want to restrict his access to their devices, perhaps allowing only Internet access. If members of a household set up shared folders to share

photos, music, and videos among multiple devices in the home network, they may want to protect these contents from unwanted access.

Currently, most home networks assume by default that the local client devices and their users are trustworthy. They do not restrict internal client devices on the local network from accessing home network resources at all. To control access for internal client devices, users need to explicitly define the access rules at the router by using an IP address and port. This requires extensive technical knowledge, including an understanding of IP addresses and port numbers, pairs of source-destination hosts and ports, packet forwarding and dropping at a router, and the methodology for composing corresponding access rules.

In the case of external device access, the home network, by default, blocks all incoming access from external devices. Network Address Transmission (NAT) allows access requests coming from the internal network to the Internet and responds to those requests, but drops all incoming requests from the Internet to the internal network. Therefore, client devices cannot operate as a server with regard to the external network. To allow incoming access from the external network, users need to do port forwarding. For instance, if a request on port 80 from the Internet looking for a web server on the home network is blocked by the NAT system to allow the request, users have to define a port forwarding rule on the router and forward the request to the web server. Port forwarding requires the same technical knowledge as controlling access for internal devices as described in the previous paragraph.

Another way that users can restrict access is by running a firewall (e.g. Windows Firewall) on individual client devices. In my formative study, some expert and intermediate users used firewall software on their individual PCs. Firewall software filters incoming access requests, but has little ability to monitor or filter outgoing ones. Users need to explicitly define access rules for outgoing access requests using an IP address and port.

In my work, to control access for internal client devices, I provide users with ways to decide access policies for four types of home network resources – client devices on the network (e.g. media servers or printers for visitors or other family members), the Internet, applications (e.g. p2p, web, etc.), and websites (e.g. inappropriate websites whose access parents would want to limit). However, in the future, I expect that a more detailed categorization of the types of home network resources will allow users to more finely tune access control. To control access from external client devices, I provide users with ways to decide access policies for server applications such as web and ftp.

3.1.3 Network Monitoring

Network monitoring includes measuring and analyzing the home network traffic and provides a real-time view of network traffic status of the home network. It allows users to watch the available network bandwidth, the bandwidth usage of each device, or the entire home network. Further, network monitoring helps users figure out the bottleneck points of the home network when they confront network speed problems. For instance, if they are watching a live lecture on the Internet, and they suddenly experience serious lag or even discontinuance, by checking the current status of the network traffic, they should be able to know if the lag is because of other devices sharing the home network or if the cause is a serious traffic jam on the Internet. In addition, network monitoring allows users to monitor the health of the home network, helping them infer network problem sources. For instance, if users experience a network application problem with a specific device, the problem source could be that individual device or the home network itself. In this case, if the users see no incoming network traffic to the home network, they can guess that their home network itself has a problem. Otherwise, it is highly likely that the device has a problem.

There are many tools that support network monitoring, ranging from command-line tools such as “netstat” to complex GUI-based tools such as “ntop”. These basically

capture all incoming and outgoing packets passing though the network and sort them according to host names, port numbers, and transmission protocol. In addition, GUI-based tools provide comprehensive visualized reports and charts to help users analyze network behavior. Nonetheless, these tools are not appropriate for everyday residential users since they require that users be able to decipher packet-level network traffic.

Some users in my formative study check the network speed of their individual devices through information that network applications provide. They check file download speeds by using file download program. Some use websites that provide a network speed checking service. However, many users in my formative study expressed a desire for a really easy way to show what is going on in the network. Some complained that there was no explicit way to monitor network performance or to detect where network speed bottlenecks come from.

In my work, I provide a way to check the traffic of the home network. To do this, instead of using packet-level network traffic representation, I use a higher-level (application-level) representation.

3.1.4 Resource Management

Resource management deals with the policies for allocating network resources, especially bandwidth and network transmission priority. Typically, the home network has one central open channel, a gateway router that connects all home network devices to the outside broadband Internet. This implies that all the devices and applications share, and most likely compete for, the available network capacity. As the home network becomes crowded with bandwidth-intensive applications or devices, and as family members compete for limited bandwidth to stream videos, make online phone calls, and download files, competition for resources will become more common.

There are several situations for which user-driven QoS control has potential. First, the home network has transitioned from a data network into a combined multimedia

network delivering voice and video. Internet TV, Internet radio, and Video on Demand applications require significantly more network bandwidth than web, email, or other network-related applications. These heavier domain applications are very sensitive to network bandwidth and create noticeable interruptions when the bandwidth requirement is not satisfied. In this case, users may want to give those applications high priority for bandwidth usage. In addition, users may want to give high priority to time-sensitive applications such as VoIP or real-time games, which require the lowest latency, while slowing down less time-sensitive applications such as file transfers, which can afford to slow down when urgent data is coming through (Palm 2004; UPnP QoS Architecture 2.0 2006). As another example, health-monitoring devices in a ubiquitous home environment may regularly need to transmit health information at a fixed time of the day. In this case, users need to give these devices the highest priority over any other devices or applications.

In the current home network infrastructure, the router is responsible for QoS of the home network, and the router, by default, serves all network traffic with the same priority. To set different priorities, users need to create explicit traffic shaping rules using tools such as “iptables” and “tc”. Creating traffic shaping rules requires extensive technical knowledge, including an understanding of packet types, transmission protocols (TCP/UDP), packet classification and scheduling, bandwidth assignment, and data transmission rate. Recently, some routers, for example, Linksys, have started to support user-driven QoS services using various packet scheduling algorithms such as CBQ and HTB. UPnP QoS Architecture 1.0/2.0 (UPnP QoS Architecture 2005/2006)) also provides a user-driven QoS audio and video traffic stream in the middleware layer. This allows users to define rules to prioritize specific streams.

In my work, I propose that a user-driven QoS control is a very effective method for home users to allocate home network resources based on their needs.

3.1.5 Help and Troubleshooting

Users need to know what management controls are available in the home network and how to control them. For such knowledge, users often use manuals, ask other people, or use online information.

Users also need to troubleshoot the home network in order to keep it working as they wish it to. Users often confront network connectivity problems and network speed problems such as dropped/refused network connections and long download times. They feel that these problems are some of the most frustrating aspects of computer use (Bragg 2000). Network connectivity problems occur for various reasons – a malfunctioning ISP, a malfunctioning router, or weak wireless signals, for instance. Network speed problems also occur for various reasons such as too much data traffic or weak wireless signals.

For troubleshooting, skilled network users can apply various network diagnosis tools such as “ipconfig”, “ping”, and “traceroute”. “ipconfig” displays all current TCP/IP network configuration values of a client device. “ping” and “traceroute” can test whether a particular host is reachable across the IP network or not. These tools usually run on client devices, and many diagnostic tools built into operating systems are based on these simple tools. Skilled network users also use “nstat” and “ntop” for network performance troubleshooting.

Unlike more skilled network users, many residential users are lost when they confront network problems, often just following the strategy of systematically rebooting the client devices (Bly et al. 2006). In fact, many intermediate and novice users in my formative study rely on very simple physical actions such as resetting/unplugging and replugging. Then for further help, they call their ISP, device vendor, or other people that they know.

To help mitigate some of the problems mentioned above, my current work seeks to redesign a help method for home network users. In my work, help will be provided only for the Eden features, not for all home network features. The help is especially

important for intermediate and novice users because they do not have much prior knowledge of home network functionalities or how these functionalities work. Many users in my formative study complained about "unusable" manuals, which had too many technical words. Some users suggested a video or animated instructional kit which would explain how to create and maintain a home network. One novice user also mentioned that it would be great to use figures or animation to make home network management easy to access and repair.

Another goal of this current work is to help users troubleshoot their home networks with an easy-to-use interface. I focus especially on network connectivity and network speed problems because they are the primary network problems that users confront. To troubleshoot these problems, I utilize simple diagnostic tools ("ping", "traceroute", and "ntop"), together with very simple heuristics,. Instead of asking users directly to use these diagnostic tools, I provide a higher-level graphical user interface for troubleshooting. Although I currently rely on existing simple diagnostic tools, in the future, more intelligent tools will be better able to troubleshoot by using some heuristics or machine learning based on the history of a network's configurations and usage.

3.2 The Role of Eden and the User in Home Network Management

In this section, I describe the assumptions I have of the home network infrastructure that underpin my work. I then discuss why users still need to interact with the home network infrastructure even though some infrastructural features are already automatically manageable by the network.

3.2.1 The Role of Eden in Home Network

Eden is built upon the IP network and automatic IP configuration technologies. The IP network requires configuring IP parameters such as the IP address, DNS servers, gateway IP addresses, and subnet masks for each device on the network. There are many

technologies that try to remove all manually configured IP parameters. One such example is the Dynamic Host Configuration Protocol (DHCP) (Droms 1997). DHCP allows client devices to obtain an IP address as well as allowing them to obtain other IP network parameters. Another such technology is Zeroconf (Cheshire and Steinberg 2005), which enables devices on the IP network to automatically configure themselves and be discovered without manual intervention.

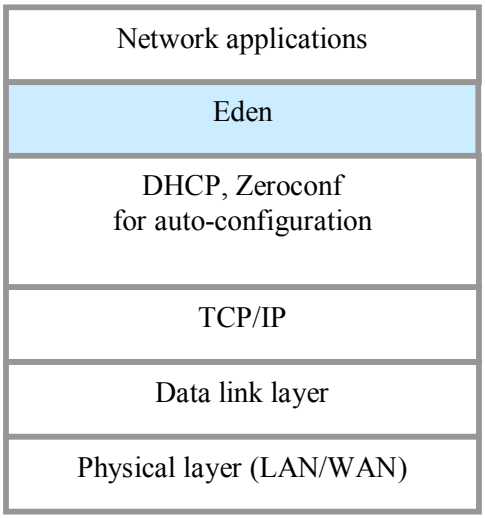


Figure 8: Eden position in the network protocol stack

3.2.2 The Role of the User in Home Network Management

With respect to membership management, it is solely the users' role to decide which devices should or should not be in the home network. The most desirable form of membership management for most users is a fully automated one, wherein the user simply selects a device to be added or deleted, after which the network management system takes care of all the technical configurations. Ideally, users just express their intention of adding or removing devices on the graphical user interface, and then the network management system takes care of all technical configurations.

Auto IP configuration technologies such as DHCP and Zeroconf make it unnecessary for users to do all IP-related technical configurations. Therefore, if users want to add wired devices, all they need to do is plug those devices into LAN ports. However, if users use a secure wireless home network, they need to get involved in technical configuration work in order to add client devices. They need to make the wireless home network secure by doing some configurations to the router. They also need to do some wireless security configuration for client devices. Furthermore, many small devices with little or no user interface will likely be in the home network in the smart home (e.g. Park 2003) and ubiquitous home (e.g. Kidd 1999). These devices are highly likely to use wireless technology to better handle mobility or physical constraints. In such cases, users will certainly need to get involved in technical configuration work for these devices.

In addition to adding client devices to the home network, removing client devices from the home network requires user decisions and some technical configuration work at the router (e.g. reclaiming an IP address or doing MAC filtering).

Such involvement of users in membership management will continue even with Internet Protocol version 6(IPv6). IPv6 solves the shortage problem for IP addresses by having a much higher number of available IP addresses, so it can assign each single device in the home network a public IP address, unique on the Internet. However, with IPv6, assigning an address to a device may not even be necessary since DHCPv6 (Droms et al. 2003) also configures IP-related parameters for each device on the network. Nonetheless, IPv6 does not tackle the issues of a secure wireless network or removing client devices.

Eden removes the need for all manual membership management configurations and lets users express their decision by simply directly manipulating client device icons on the GUI.It achieves this by keeping the wireless home network open so that any client devices will be detected by the home network. However, Eden prohibits any device from

accessing any home network resources until the user gives a specified cue on the Eden user interface to add the device. This has the same effect as the device not being connected to the home network at all. Eden has another option to gain the same effect. Eden can make a DHCP server not automatically assign IP configurations to the selected client devices until the user gives a specified cue on the Eden user interface to add those devices. This, however, requires slightly modifying the default DHCP server. These approaches do not require extra software at the client devices, which are thus compatible with the current home network infrastructure technology. However, the one potential drawback to Eden is that unwanted wireless traffic could possibly be recognized since it is occurring on an open wireless network.

There could be other options to facilitate manual, configuration-free membership management for Eden. For instance, two wireless networks could be used – one public and the other secure. Client devices would then first be detected by an open wireless network, one which has no access to the home network. Then, when users make the client devices a member, the devices would be moved to the secure network. Two wireless networks could be implemented by various technologies such as dual radio base stations (e.g. AT3100 series), the VLAN technology (e.g. Apple Airport Extreme), or two wireless network cards. This approach would remove the risk of wireless traffic being recognized. However, it would require extra software at the client devices.

Eden takes away all manual configurations from users to remove client devices by MAC filtering or modifying the DHCP server.

With regard to access control, decisions on access permits can not be automatically made by the network, but should be made instead by the users themselves. For instance, parental access control on a specific website should be done by parents, not by the network.

With regard to resource management, researchers designed QoS for bandwidth-intensive applications, such as IPTV and multimedia applications, in the context of the

home network (Cuomo 2008; Lee et al 2005; Palm 2004). They implement QoS policies at the data-link layer or at the home network gateway router. All these efforts try to adjust QoS for multimedia data at the system level, not at the user-level. However, there are cases that require users to become involved in QoS management according to their personal preferences.

3.3 Limitations and Caveats of My Work

In this section, I discuss Eden's limitations. Some of these limitations are due to technical issues, while others have been designed for a purpose.

The first limitation is that Eden supports only basic residential user-centered management tasks. It tries to cover most home network management tasks provided by general routers. However, it does not add intelligent features for home network management. For instance, it does not take into account automated management services based on the history and patterns of a users' network usage. This is because the focus of Eden is to design a new user interface model rather than add specific intelligent features to existing home network management approaches. In addition, Eden does not provide residential users with more advanced network management tasks such as static IP address settings for client devices, multiple wireless security options, or packet-level network traffic monitoring. The reason for this is that two of the goals of Eden are 1) to expose the internal technologies of the home network as little as possible (unless this prevents users from achieving their goals) and 2) to convert low-level network features into high-level network features that are more meaningful to residential users.

A second limitation is that Eden does not provide a high order of network troubleshooting. It provides only basic information about the status of the home network and each device in order to help the user infer network problem sources. Eden does not use any machine learning mechanisms to infer network problem sources. This means that there are problem sources that Eden can not detect. For instance, there is no way for Eden

to tell the user about any un-plugged cable problems. Eden also can not detect compatibility problems among devices, for instance, one between wireless security 802.11b WEP devices and 802.11g WPA devices (Bly et al. 2006).

Third, Eden cannot directly deal with client device problems. This is because Eden takes a centralized management approach. That is, Eden requires no changes on client devices. The centralized approach restricts the potential of advanced features that client devices might otherwise provide. For instance, the router may not necessarily be able to determine all application types, only those with well-known port numbers. There are many other applications that do not use well-known port numbers. However, client devices can get that information directly from applications upon running them, which would provide richer network monitoring for users.

Despite these limitations, I chose the centralized network management approach for several reasons. First, it makes Eden compatible with the current home network architecture. It also requires only minimal extra network traffic overhead while still being able to remove the availability and partial viewpoint issues of the distributed management approach. In addition, most of the basic network management can be done at the router because the router plays a core role in network configurations and policy settings. Finally, the centralized approach can reduce some usability problems that users experience with their home network. The Internet supports just the best-effort service for data delivery between end points (gateway routers in the case of the home network). Hence, it is the end user who has to be responsible for setting up and maintaining the home network. The complexity of this responsibility makes home network management difficult for most residential users. One way to simplify such responsibility is to place more intelligence between the Internet and the end users (e.g., in the home gateway router), thereby placing less demand on the end users (Calvert et al. 2008). Eden tries to follow such an approach. For instance, Eden places no technical demand on the end users for membership management while placing more intelligence on the gateway router. In this way, Eden

reduces the usability problems associated with configurations for membership management.

3.4 Target Users

The goal of Eden is to assist general residential users who lack the technical knowledge to manage their home networks. Home network management has been reported as a frustrating and tedious experience for most home network users (Edwards and Grinter 2001; Grinter and Edwards 2005; Chetty, Sung et al. 2007). Managing the home network requires knowledge of the internal architecture and functionalities of the home network. Users who have obtained such knowledge through training or experience may not have difficulty with managing their networks even with technically advanced network management tools. However, many home network users have not had such training or experience. They have, at most, informal or very little technical knowledge. Nevertheless, they need to manage their home networks themselves. Otherwise, they have no choice but to rely on others every time that their network requires some kind of management.

Eden aims to assist basic home network users by providing an intuitive, easy-to-use user interface. Through its user interface, Eden can convey the basic technical concepts of the home network in a self-explanatory manner. On the other hand, it can hide the internal technologies that may not be necessary for users to know about in order to achieve their goals. In this way, Eden will help users who have no formal training or little previous experience self-managing their home networks.

I categorize users into three groups - novice users, intermediate users, and expert users - based on their level of technical knowledge of networking. Identifying the technical knowledge of users will be a two-step process. First, the users will self-report on their previous networking management experience. Then their self-reports will be confirmed through networking knowledge tests which I will administer during my

evaluation. The reason that I rely on self-reports on previous networking management experiences is that, by and large, the users' experiences with home network management can reveal their level of technical knowledge. In other words, users who manage a network themselves are likely to have more technical knowledge than those who do not. In research by Poole et al (2008), study participants were categorized into three groups based on their degree of engagement with home network management. The three groups were consumers (who use the network but do not engage in any network management), assistors (who assist with network management but do not play a leading role), and experts (who play a leading role). These three groups had different conceptual models about home networks according to their engagement in network management. Those who had more engagement with home network management tended to know more about the inner workings of the home network. Users with no engagement in any network management tended to view the home network only by what they could physically see.

Among the three groups of users, the primary target users of Eden are the novice and intermediate users. Novice users will be the ones who use the home network with no engagement in network management. These are users who use networked devices that are ready to use. This group of users may not understand technical networking terminologies. They may not understand which hardware components are necessary for home networking. They might understand basic connectivity issues, but they may not recognize the need for admission control, performance monitoring, and resource management.

This work seeks to examine how the new interaction model of Eden can enrich novice users so that they begin to understand the conceptual model and functions of the home network. It will also examine the usability of Eden - which interface metaphors novice users easily understand and which they do not. Some may argue that novice users would not be interested in managing their home networks, simply choosing only to rely on others. However, I hope an easy-to-use network management system will motivate even novice users to try to manage their home networks. My goal for these users is to

move them from “no management skills” to “basic management skills” so that they do not have to rely on others every time they need to carry out basic management.

Intermediate users are the ones who are able to do some network management work (e.g. connectivity configuration for client devices – because they often are required to do this kind of task in their everyday life), but they do this with only limited knowledge. Self-reported intermediate users in my formative study often said that they had sufficient technical knowledge to connect wired/wireless client devices to the home network. Some of them check network speeds in various ways such as by using network applications. Some of them try to troubleshoot their network connectivity problems using troubleshooting tools that are built into the operating system. However, some intermediate users in my formative study were not able to perform any management tasks in their home network other than those mentioned above. Many intermediate users could not perform most of the network management tasks described in Section 3.1. For instance, some of them wanted to do access control (e.g. parental control, shared folder access control), but they did not know how. As discussed in Section 3.1, some users wanted to monitor their home network’s performance, but they did not know how to do this. In addition, many intermediate users, just like novice users, were found not to have even very basic knowledge of how the home network works as a distributed system, what control parameters the home network provides, or how they could set those control parameters. Therefore, their ability to maintain their home network was very limited to what they could do only the at client device level.

With intermediate users, I want to examine how well they come to understand the concepts and functions of the home network through Eden and how much better they can perform tasks with Eden in terms of effectiveness and efficiency, compared to the network management tools they have used in the past.

Expert users are not the primary target group of users for Eden since they are the ones who can perform network management tasks with current network management

systems. With their experience and rich knowledge, they may be able to troubleshoot better than Eden. Therefore, I include several expert users just to broaden the user sample. I expect that they will be able to give feedback on the usability of the proposed system.

CHAPTER 4

FORMATIVE STUDY

The formative study was designed to serve two purposes. One purpose was to get ideas on the tools that users rely on for their home network management, the usabilty problems with those tools, and desirable features for home network management tools. Since there were no empirical or statistical study results of the tools as of yet, the findings from this formative study helped guide my selection of counterpart systems that will be compared to my system during the evaluation stage.

The other purpose of the formative study was to get feedback on several design alternatives for visual representation and task activation paradigms of the home network in order to inform the choice of the final sysem. Since the choice of visual representation and task activation is the key factor for the effectiveness of direct manipulation, how to design them was important (Shneiderman; Frohlich 1996).

In the rest of the chapter, I first describe the formative study methodology and then report the findings.

4.1 Study Methodology

The formative study consisted of two sessions, a questionnaire session and a design evaluation session. In the questionnaire session, I solicited user input on existing network management design tools and asked them what they would like to see any new tools be able to do. In the design evaluation session, I showed the users low fidelity prototypes of the three design alternatives for visual representation paradigms and the two design alternatives for task activation paradigms. I then asked the users to perform sample tasks with each design alternative. I finally gathered feedback on the three design alternatives.

For this study, I recruited 14 study participants. Nine of them were males, and five of them were females. The age range of these users varied from 18 to 55. The age variance was purposefully done because the ages of actual home network users varies considerably.

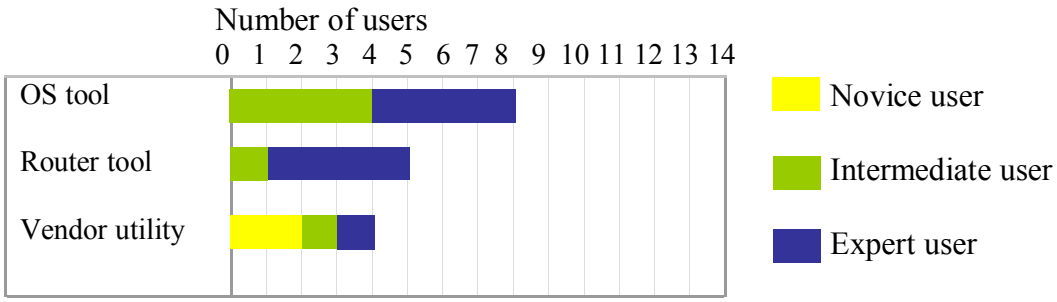
Participant recruitment was done by word-of-mouth and random selection in public locations. Five participants were self-described novice users. They had never done network management and had only used devices that had been networked by others. Four of them were self-described intermdiate users who had obtained informal knowledge from people around them, online sites, or books. Five of them were self-described network expert users. They had obtained technical knowledge from network classes during undergraduate and graduate school. Although expert users are not the primary target users of the proposed system, I included them to broaden the user samples, and the experts were also expected to give comments on the usability problems of current network management tools based on their network management experiences. They were also welcome to give feedback on design alternatives from their expert perspectives which included much more techical knowledge of networking.

Thirteen out of the 14 participants had wireless networks in their home. Most had desktop PCs and laptops connected to their home network. One third of the participants had mobile computing devices such as a PDA connected to the home network. Two users had networked game devices.

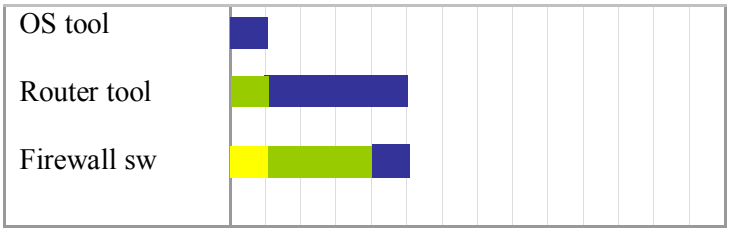
4.2 Tools That Users Rely on, Usability Problems, and Desirable Features

4.2.1 Tools That Users Rely on

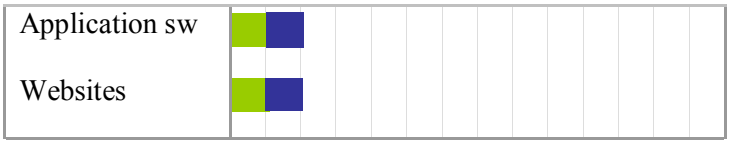
Figure 9 shows the tools that users rely on. Overall, most users relied on network management tools built-into the OS and the router for most management tasks.



(a) Tools for device configuration

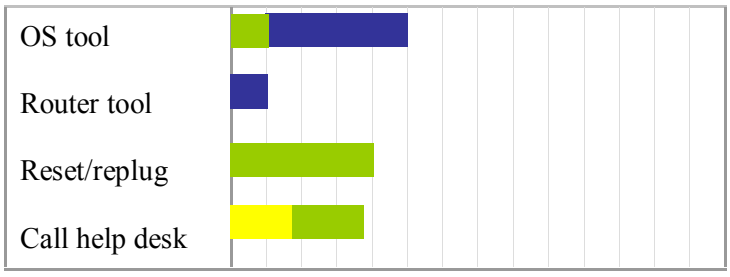


(b) Tools for access control



(c) Tools for network monitoring

(d) Tools for resource management



(e) Tools for help/troubleshooting

Figure 9: Tools that users rely on for network management

For memberhip management (adding and removing a device), most of the participants used default tools built-into the OS and the router, although there were two users who used utility software provided by their network device vendors, for instance, Intel. These participants used built-in tools because they did not need to install additonal software themselves. However, they mentioned that those tools, especially the ones in the router, provided too many unused low-level networking options and used terminologies unfamiliar even to expert users.

For access control, most intermediate and expert users relied on built-in tools in the router and firewall software running on their individual computers.

For network monitoring, unlike their approach to membership management and access control, users checked the nework speed of an individual device in various ways. For instance, one expert and one intermediate user checked on the network speed by using file downloading applications and video streaming applications. Several users used websites that provided a network speed checking service in order to test their computing devices. However, many users mentioned that they had never checked the whole network speed because they did not know how to do it.

None of users had ever done resource management. There were two basic reasons for this. Some users mentioned that they felt no apparent need to do resource allocation. For instance, one user stated, “I don’t want to care about any priorities of network applications or devices; whenever I think some application consumes too much network resource, I just turn them off.” On the other hand, other users mentioned that they wanted to do resource management,but simply did not know how.

For help and troubleshooting, the users in the study relied on tools built into the OS and the router as well. However, the novice users tended to rely on very simple physical actions such as resetting, unplugging, and replugging of devices and external help from their ISP or device vendors. This study result mirrors the study results of Bly et al that when users are at a loss regarding how to pursue fixes, they often just take a

strategy of systematically rebooting devices (Bly, Schilit, et al. 2006). The users in the study complained that it was hard to detect what caused a problem at first glance with built-in OS tools. One user expressed his desire to be able to troubleshoot easily, saying, "I just want to get simple, direct indication about network problems and solutions. For instance, like, 'Your router is off.' (instead of the multiple steps that he needed to follow to diagnose network problems).

4.2.2 Usability Problems of the Network and Tools

This section describes usability problems commonly mentioned by the formative study participants. Although the findings do not cover every possible usability problem, they gave insight into overall usability problems and some design implications for a new kind of management tool.

Hard-to-understand and hard-to-use network. This was the most mentioned problem by the study participants. Not surprisingly, intermediate and novice users emphasized it in statements such as the following: "Everything should be easy to see, understand, and use." "Plug and play network is the best." "Making the home network easier will allow less educated people to use computing/networking technologies more easily." They also emphasized a desire for easy troubleshooting. Most indicated that disconnection was their biggest problem and that they had no idea what to do when the network was disconnected.

One expert user mentioned that there were too many wireless security options, and that whether he wanted to or not, he had to take a look at them and choose one. This user didn't not care what kind of wireless security options existed, only whether his home network was secure or not.

These kinds of comments confirmed again the prompt need for a home network management tool that is easy enough to use for such home network users without requring too much underlying technical networking knowledge.

Hard-to-find network tools. This was also often mentioned by many users. They complained that they had no idea what tools they needed to run or how to get to those tools to perform specific tasks. Since tools support some aspects of network management, the users had to run different tools for different management tasks.

One user addressed the usability problem of getting to the built-in router tool. To get to the tool built into the router, users usually have to know the IP address of the router on the browser, something not familiar to many users. Furthermore, different routers have different default IP addresses. For instance, Linksys routers usually use 192.168.1.1 as their default IP address, and DLINK routers use 192.168.0.1.

The problem of tool accessibility suggests that it would be good to provide users with an all-in-one network management tool that supports all network management tasks at one time, tool that can be accessed easily by ordinary users.

Inconsistent user interface of management tools. The study participants also commonly mentioned problems with inconsistent user interface among management tools. This is because tools are different from vendor to vendor, from device to device, from OS to OS, and from task to task. Although the vendor, device, and OS inconsistencies may not be solved by one management tool, I believe the task to task inconsistencies can be alleviated by providing an all-in-one management environement.

Invisibility of the home network. The **"**invisibility" of the network was an issue for the participants, especially when they confronted networking problems such as disconnection and slow speed. The participants mentioned that they had no easy ways to check the speed of the whole home network or indivdual devices. This suggests that there should be a way for users to oversee the whole network as well as the individual devices. Several users also suggested that, for the purpose of privacy, it would be helpful to see which devices are communicating with which devices in the home network.

Unusable manual or instructions. Manuals were too difficult to use, according to some study users, because they contained too many technical words that were not

understandable or helpful. One user mentioned a poor router instruction guide, saying, "When I bought a router and brought it home, I did not know what to do. I plugged the router in but then had no idea what I should do next?" One user expressed a wish for an instsructional video kit that would explain how to create a home network. One novice user suggested the use of figures or animation to help users build and manage the home network. This suggests that more understandable forms of help and instructions should be created for users.

Need for easy and secure file sharing among devices in the home network. Although this is not exactly a usability problem for network management tools, one user pointed out the usability problems of file sharing within the network. Currently, to share files between two computers, both computers should be on; otherwise, users cannot share files between the two computers. This user wanted to have a home network that would automatically buffer file sending requests to a turned-off computer and then send the requests to that computer when the computer was up. This user also emphasized a need for data privacy in file sharing. He was concerned about others being able to see his private files.

The usability problems of file sharing are outside the scope of this research, but data privacy in file sharing will be addressed by access control in this research.

4.2.3 Desirable Features of a Management Tool

This section discusses the features that study participants desired in a management tool.

Universal accessability was the most commonly mentioned concern for the study participants. They wanted to have the management system that they were able to access with any computing devices in the home network no matter. At the same time, even though the participants preferred a management system accessible with any computing devices, several expert and intermediate users mentioned that they preferred a centralized

network management system for optimum technical efficiency. This desire is addressed in my system by the web-based management environment, whose centralized network management approach allows universal access from any computing devices. Details of this are discussed in Chapter 6.

With regard to a holistic environment for all tasks versus separate tools per task, all the users but one expert user absolutely preferred a holistic environment. The reasons for such a preference were the following: 1) A holistic system simplifies management tasks by using one program in one place; 2) It provides a consistent look and interface, thus requiring less time for users to to learn than those of multiple management tools with different looks and interfaces; 3) It allows users to recognize all available network settings and options at a glance and thus gets rid of chances to miss some management tasks. One expert user preferred a separate, specific tool.

Finally, several users emphasized that they did not want to be required to install extra software installation on a computer or on a computing device. They also did not want to have to incur any extra cost for a management system. This suggests that it would be better to provide users with management tools that are built into networking devices.

4.3 Visual Representation Paradigm of Home Network

4.3.1 Three Design Alternatives

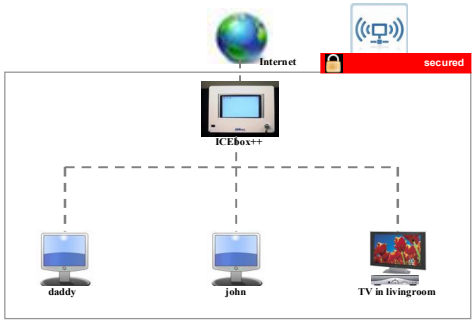
The visual representation for the home network should provide users with enough understanding of their home network upon which user interaction is implemented. At the same time, the visual representation should be made easy for users to understand by taking into account the mental models that users have of users their home network and their management tasks.

To get ideas for the visual representation of the home network, I designed three representation paradigms, in the form of low-fidelity paper prototypes with sample

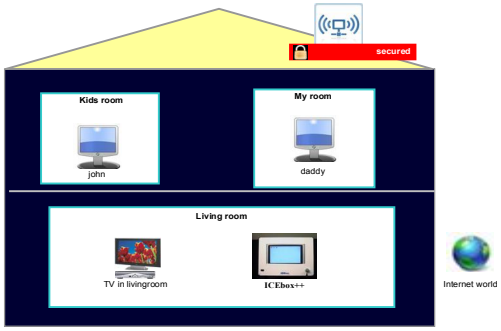
management tasks in the five management categories (as discussed in Section 3.1) that users perform on them.

Paper-prototpyes can have limitations to properly show the dynamic nature of the home network such as traffic flow. However, the primary purpose of this formative study is to receive early feedback on the overall representation paradigm, I believe statically visual objects without the dynamicity can give enough of a picture for the primary purpose of the formative study.

The three representation paradigms are (a) a tree representation, (b) a spatial/organizational representation, and (c) an abstract representation (Figure 10). These representations are on a continuum of concrete, technical representation to casual, less technical representation.



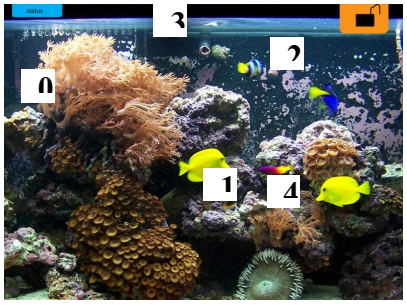
(a) Canonical tree representation



(b) Spatial/organizational representation

Legend
0. Home – home network
1. Front yard – wireless network
2. 3. 5: people – computers
4. windows/blinds: firewall

(c) Abstract representation - #1

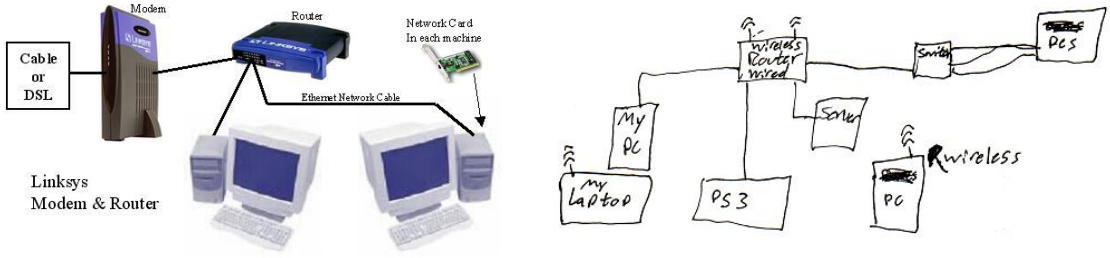


Legend
0. tank – home network
1. fish - hosts
2. bubble - bandwidth
3. upside - firewall
4. smart fish – help assistant

(c) Abstract representation - #2

Figure 10: Three design alternatives for the home network

(a) Canonical tree representation. This representation is the traditional representation of the home network. With a home gateway router at the top-root, devices currently active or once active are positioned on a leaf of the tree as shown in Figure 11 – (a). This representation best respects the logical topology of the home network. On the other hand, it could be unfamiliar at first glance to novice or intermediate users if they have not been trained in the underlying architecture of the home network. Many expert and intermediate users used this representation in their sketches of the home network in my formative study and in previous work as shown in Figure 11 – (b) (Poole et al. 2008)

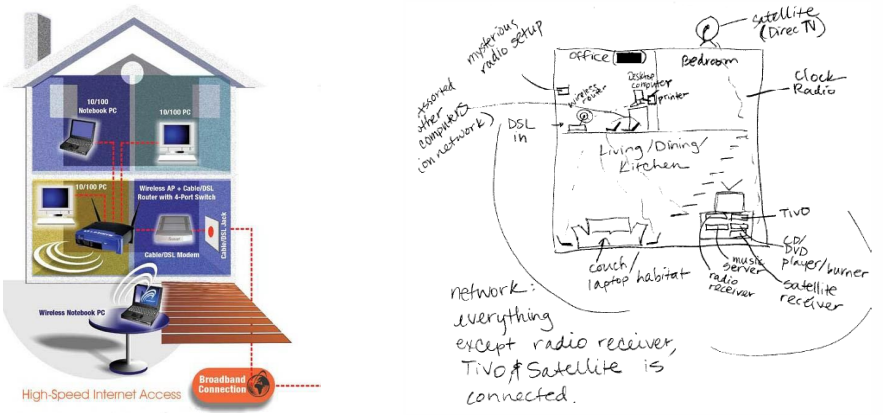


(a) Traditional network representation (b) A formative study participant's sketch

Figure 11: Canonical tree representation

(b) Spatial/organizational representation. This representation integrates the spatial/organizational characteristics of the home. Although this representation is not in home network management tools, it is very commonly seen in advertisements and home network envision flyers (Figure 12 - (a)). Many home network users are exposed to this representation in reality. Such injections of the spatial/organizational concept into the home network representation were also often seen in intermediate and novice users' sketches of home networks in the formative study and previous work as shown in Figure 12 – (b) (Poole et al. 2008). This representation provides a more familiar and intuitive look for the home network and a good mapping between computing devices in the physical home and those in the logical representation. Further, this representation can

integrate the conceptual metaphors of high-level controls of the home network. If, for example, parents want to do some access control of harmful Internet sites for their child, one good conceptual model for parental control would be to put the computer of their child into a kid's room and let the parents set the control options (e.g. blocking those harmful Internet sites). On the other hand, this representation can be overwhelming in the sense that it adds more features to the home network itself.



(a) A home network flyer (b) A user's sketch of a home network

Figure 12: Spatial/organizational representation

(c) Abstract representation. This representation is more casual and abstract in nature. Home network components are represented as other abstract objects. For instance, in Figure 10 - (C) - #1, People in Wi-Fi area represent computing devices connected to the wireless home network. Windows on the Home represents network ports, and actions such as opening and closing those windows open or close network ports. Similarly, in Figure 10 - (C) - #2, the home network is represented as a fish tank, and the home network components are represented as the objects in the fish tank. Such abstracted representation was used in several research projects such as PSDoom (Chao. 2001), a process management system that adopts the user interface of the game Doom for an intuitive environment for non-technical users. In PSDoom, each process is represented as

a monster, a game character, and interacting with monsters is equal to performing actions on corresponding processes. One drawback to abstract representation is that it can sometimes require even more cognitive effort on the user's part to map home network components and corresponding visual objects. Since abstract representations can result in very different responses from users according to how abstract the representations look, I designed two different representations to increase the generality of the study .

4.3.2 Study Results

4.3.2.1 What Are the Pros and Cons of Each Design Alternative?

With respect to the canonical tree representation, intermediate and expert users pointed out the good points of the tree representation, while all novice users were very negative toward it. Study users made the following comments:

- The link among devices presents a clear indication of the hierarchial network topology and connectivity status. The representation of the network topology can help troubleshooting. For instance, if a router is down, devices under the router on the tree are not assumed to be working.
- It is simple, and only necessary components are represented. If you have a bit of computing and networking knowledge, you would be able to easily learn and understand the network.
- It is hard to understand what the tree means at a glance (this was mentioned by all novice users and some intermediate users).

With respect to the spatial/organizational representation, novice, intermdiate, and expert users were all positive in general. Following are (some of) the pros and cons of the spatial/organizational representation that users mentioned.

- It provides a good mapping with physical locations of the devices in the home. It provides more direct instructions, more relative to home "real" situations, thus makes more sense.
- It would be easy for someone with little or no networking skills to pick up on.
- The spatial model of the home network – the physical boundary to represent the logical home network boundary – is easy and intuitive to understand.
- High-level features, such as access control, associated with the Home and rooms are (a) very useful and easy-to-understand approach.
- However, it does not tell the hierarchial network topology information. It also can cause confusion to understand the true underlying network configuration architecture.

With respect to the abstract representation, all intermediate and expert users gave the following negative feedback:

- It does not tell the hierachial network topology. This is problematic when troubleshooting.
- It requires mapping between neworking objects and corresponding objects. That is, it requires extra work to make mapping clear.
- It might be good for passive display, but not for task-oriented work.

Some novice users, on the other hand, gave positive feedback on the abstract representation model. They stated that the abstract representation was easy to understand and learn. Due to their lack of prior knowledge of networking and their unfamiliarity with networking, the novice users chose the abstract representation model for its familiar and intuitive expression, regardless of the mapping problems that (the more advanced) users mentioned. However, some novice users expressed dissatisfaction similar to that of the

expert and intermediate users regarding the abstract representation model as having (requiring) too much "mapping."

4.3.2.2 Which Design Alternative Is More Effective for My Target Users?

I asked users about their overall preferences regarding the visual representations. Figure 13 shows the result per user group.

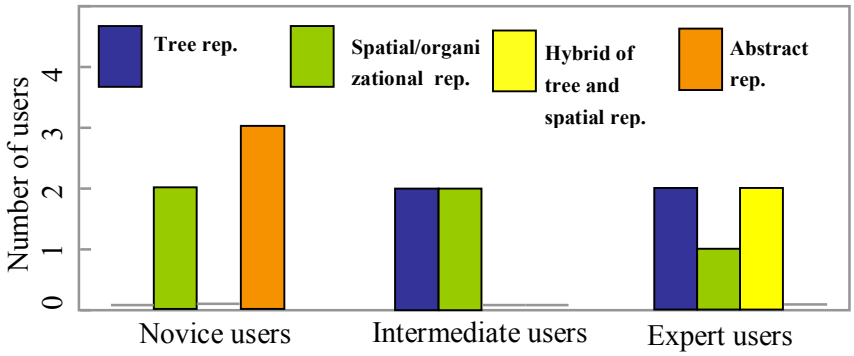


Figure 13: Visual representation preferences of each user group

The novice users clearly preferred less technical representations (the spatial/organizational and the abstract representations) because these were more familiar to them than the more technicl (tree) one.

Intermediate and expert users preferred the canonical tree and the spatial/organizational representations. Some of them liked the spatial/organizational representation's usefulness and effectiveness in its presentation of the home network. Some of them liked the tree representation's network hierarchies and connectivity information as represented by a topology link. Two expert users suggested a hybrid approach of the canonical tree representation and a spatial/organizational representation, which complements the spatial/organizational representation with the technical hierarchy and link information of the canonical tree representation.

Regardless of their level of networking knowledge, users most clearly preferred concrete, real representation (such as a device icon) over abstract representation for the device representation.

4.3.2.3 Do Users' Conceptual Models of the Home Network Match With Their Preferences for the Visual Representation Paradigm of the Home Network?

In the very beginning of the formative study, I asked the participants to sketch their home network before being given the three design alternatives. I then compared their sketches with their preferences. Figure 14 depicts the results.

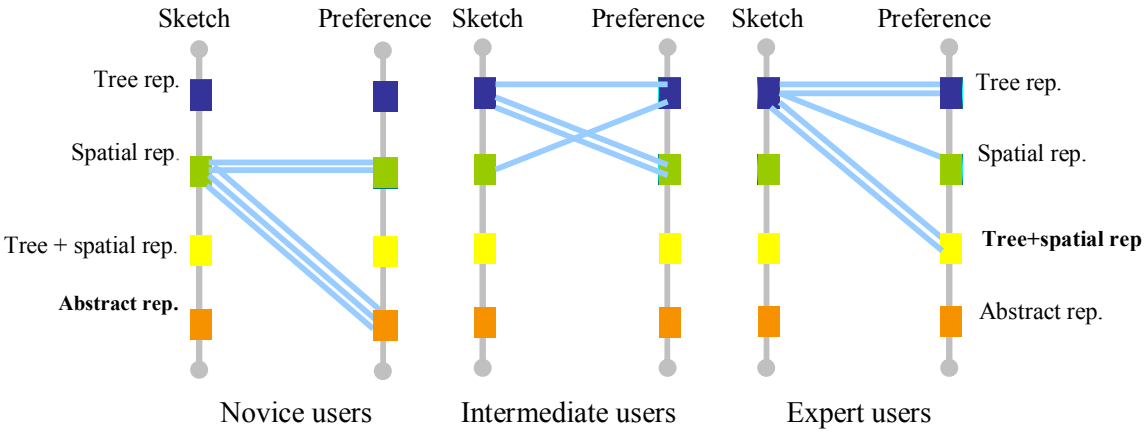


Figure 14: Users' conceptual model vs. visual representation preferences

All novice users sketched their home networks in the spatial/organizational representation. All five included computing accessories such as speakers, mice, and monitors in their sketches. They arranged computers and computing accessories in a spatial/organizational manner. Their conceptual models of the home ntework focused more on computing devices rather than on networking gear. In fact, several novice users drew only computing devices while completely omitting the router or the modem, which are the core networking devices.

Three out of the four intermediate users drew tree representations with network hierarchies. The remaining users drew only computing devices without any link among those devices but arranged them in the spatial/organizational structure of his/her home like the novice users. However, two of the three users who drew a tree representation preferred the spatial/organization representation, while the remaining two preferred a tree representation.

All expert users sketched their home network in the tree representation, but their sketches were not identical to their preferences. They drew cables, routers, wireless routers, and devices connected with links. They (apparently) formed their conceptual model on the home network through the conceptual models represented by networking classes. However, only two users chose the tree representation. The others preferred a new representation of the home network that integrated the spatial/organizational layout of the house.

Overall, it was not always the case that the mental models of the users coincided with their preferences for the representational paradigm of the home network. Although these results are not statistically significant due to the small number of participants, it gives, perhaps, an initial clue regarding the relationships between the two variables. This result also suggested the potential for a new representation of the home network management that could be helpful to all groups of users, regardless of their technical knowledge level of networking.

4.4 Task Activation Paradigm for Management Tasks

4.4.1 Design Alternatives

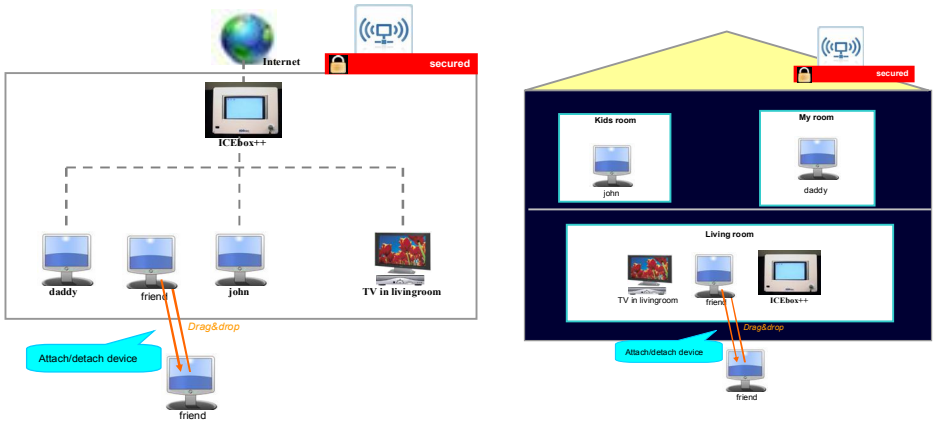
The next of designing an interaction model of a management tool based on direct manipulation concerns how to design the task activation model.

The basic task activation model for direct manipulation is the physical manipulation of visual objects, such as the drag-and-drop method. In addition, direct manipulation utilizes tools such as buttons, menus, and dialog boxes for abstract operations, all of which play a part in the action translation interface between the user's input and the object to be manipulated.

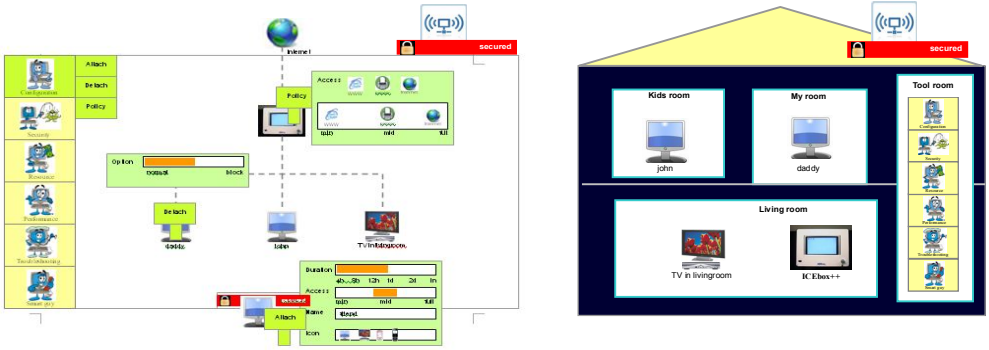
To figure out which task activation paradigm is good for users, I designed two design alternatives. One is based on drag-and-drop, and the other is based on tools. In the drag-and-drop model, the configuration settings as well as the devices are represented as graphical objects, and users can perform tasks only by dragging and dropping those configuration settings and devices. In the tool-based model, devices are represented only as graphical objects, and configuration settings are represented as options either in the menu or in a dialog box. To perform tasks on devices, users select an option in the menu and activate the option.

I applied both design alternatives to the three design alternatives of the visual for sampled tasks in the five management categories discussed in Section 3.1.

Figure 15 shows examples of task activation paradigms for adding a device to the home network. Figure 15 - (a) illustrates the task activation paradigm based on the dragging and and-dropping of a target device. To add a new device to the home network, users drag the network device inside the home network. Figure 15 - (b) illustrates the task activation paradigm based on the tool-based model. To attach a new network device to the home network, users pick a tool marked "attach" from the menu bar on the left side and then drag it to the new device. Then the tool shows some options in the form of menu that users can set for the target device.



(a) Drag-and-drop task activation in the tree representation (left) and in the spatial/organizational representation (right) for adding a device to the home network



(b) Tool-based task activation in the tree representation (left) and in the spatial/organizational representation (right) for adding a device to the home network

Figure 15: Examples of the task activation paradigm based on drag-and-drop and tool methods

4.4.2 Study Results

4.4.2.1 What Are the Pros and Cons of Each Design Alternative?

Overall, the users preferred the drag-and-drop based task activation of graphical objects for devices and configurations over the tool-based one due to the former's familiarity and simplicity.

Users mentioned the following as the the main advantages of the drag-and-drop method:

- It is convenient and familiar. (This was mentioned by intermediate users and novice users. Familiarity and easiness was the most primary reason about their choices).
- It matches best the real world metaphor. In other words, it matches the way that you do a task in reality: you go to a target object, for instance, a computing device, to perform any tasks on the computing device. This requires you just to think about the target object, not about any other tools.
- It is more fun and felt easy, like games.

On the other hand, users also mentioned some drawbacks of the drag-and-drop method which became the reasons why they preferred the tool-based design.

- Compared to the tool-based method, the drag-and-drop method does not explicitly state what users can do with the graphical objects.

Meanwhile, users who preferred the tool-based method mentioned the following reasons:

- Having information on available functions provides a better sense about the features of home network management.

- It is simple to understand and learn how it works; you just select the right option in the menu and activate it for the device you want.

Five users preferred the hybrid approach of the drag-and-drop-based design and the tool-based one. For instance, two of the five choose different models for different tasks. They preferred the drag-and-drop approach for membership and resource management since drag and drop across the physical boundary of the home network is convenient and easy to understand conceptually. However, these same two users peferred the menu-based option for network monitoring and troubleshooting.

4.5 Design Implications for the Final System

The formative study results informed the final system in several ways. As discussed in Section 4.3.1, I addressed the usabilty problems of the tools and desirable features in the final system.

The user comments on the three design alternatives suggested a 'mixed mode' representation that uses a spatial representation overlaid with logical information about the network topology and traffic flow path, which portrays the network in the familiar spatial scheme of physical home layout to all groups of home users.

The result of the task activation model led me to investigate the drag-and-drop based task activation paradigms with both devices and configuration settings represented as physically manipulable graphical objects. However, affordance should be considered in the drag-and-based design.

In the next section, I describe the final design choice of the system.

CHAPTER 5

EDEN USER INTERFACE

Eden utilizes direct manipulation based on continuous visual representation and physical manipulation of objects of interest. It represents networking devices and network configurations as interactive graphical objects which users can drag and drop to perform network management tasks.

To simplify the manipulation of interactive objects, direct manipulation usually uses metaphoric images related to the object or concept on which the task is being performed. This use of metaphors allows users to apply their analogical reasoning when determining which actions to take and how to take them. The metaphors can also help users understand the system, especially if the metaphors, the graphical representations, are very familiar to them.

Eden employs four user interface metaphors from the real world familiar to users in order to convey the basic conceptual model of the home network and to support management actions. To present the basic visual and conceptual framework of the home network, Eden utilizes the spatial metaphor of a Home and a component diagram metaphor connected by a Link-Pipe. These two metaphors support membership management and network monitoring. To present access control and resource management, Eden utilizes a badge metaphor, which converts the abstract network properties of access and QoS controls into a concrete, familiar real world object in the form of a badge (a symbol of authority) so that users can directly apply those badges to specific devices in the home network. To represent help and troubleshooting, Eden displays an assistant metaphor named Smart Guide and HomeNet Doctor. In the real world, when people do not know how to use a certain object or what is wrong with an

object, they often ask someone who knows better than themselves about the object. Eden takes advantage of the same analogy for the assistive management area.

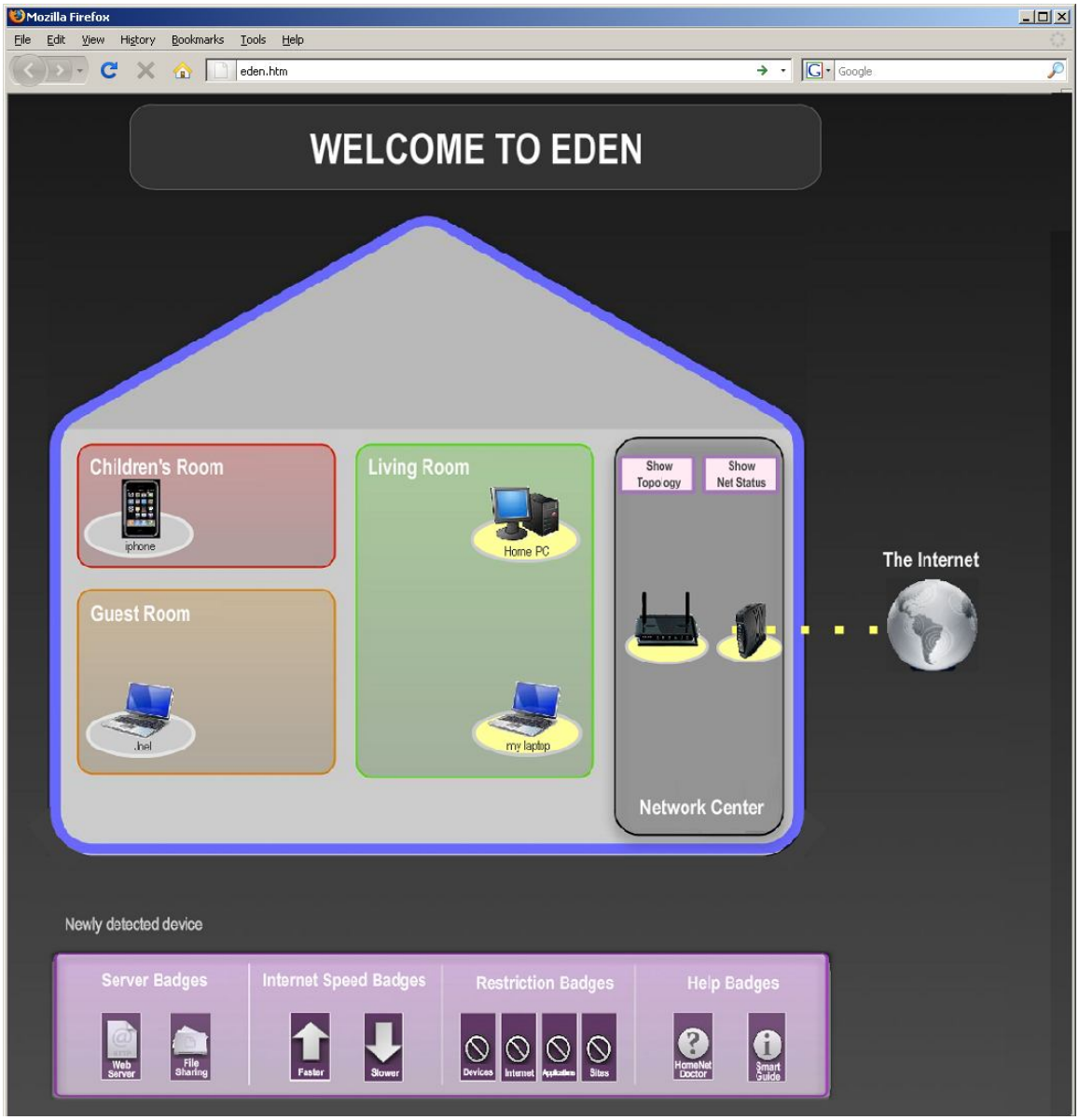


Figure 16: Eden screenshot

In the rest of the chapter, I first revisit the user interface metaphor and then discuss the metaphors that Eden adopts. In Section 5.1, I revisit the contemporary theory of metaphor that serves as a conceptual model of the user interface metaphor. Then I discuss both the roles and benefits of metaphors in the Graphical User Interface (GUI) and then the drawbacks of misused metaphors. Finally, I discuss why I decided to use the metaphor for the home network management domain.

In Section 5.2, I discuss Eden's user interface metaphors in detail and explain why these metaphors were chosen. I also discuss potential sources of confusion regarding the chosen metaphors in the problem domain.

5.1 User Interface Metaphor

Before discussing the user interface, I first summarize the theoretical background of the role of metaphor in human cognition in order to clarify the role of the metaphors in the user interface.

5.1.1 Contemporary Theory of Metaphor

The user interface metaphor is said to have its root in the contemporary theory of conceptual metaphor by Lakoff and Johnson.

> "Our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature…. In most of the little things we do every day, we simply think and act more or less automatically along certain lines." (Lakoff and Johnson 1980)

Lakoff and Johnson (Lakoff and Johnson 1980) argue that a metaphor is not a mere grouping of words but a fundamental mechanism of the human thought process, which allows us to use what we know from our physical and social experiences to get an

understanding of other abstract subjects. For instance, we often say that life is a marathon. This is not just a linguistic expression; it describes how we think of life and what actions we need to take during life. When we are born, we begin the metaphoric marathon. By saying that life is a marathon we are suggesting that life requires perserverance and endurance. There are times when we lose footing and fall, but we get back up and continue running. We have friends and competitors that run along with us. Carroll and Thomas (1982) support Lakoff and Johnson's argument. They argue that when people encounter something new, it is natural for them to use to their existing knowledge structure to understand the new information.

A metaphor is the use of a conceptual model familiar to people (a source domain) to convey the meaning of something unfamiliar (a target domain) by using knowledge in the familiar domain of people (Lakoff 1992). These two domains have structural correspondence to a certain degree but are two entirely different kinds of things in nature. In general, a target domain is more abstract while a source domain is more concrete or physical. This is obvious when we consider invisible or intangible things such as life, relationships, ideas, and/or emotions.

Metaphors highlight a certain aspect of a target domain from many perspectives in order to emphasize the correspondence between the target domain and a source domain. For instance, when we say that a computer is interactive, we are emphasizing the notion that a computer can hold a conversation with people similar to the way a person can hold a conversation with another person. A computer has the capacity to listen to a person (e.g. receive commands) and provide appropriate responses (e.g. feedback) in a human-computer language. When we say that a computer is an agent, we are highlighting the aspect of the computer that does work previously done by people, although in reality the work is the result of what people had programmed into the computer in advance.

Metaphors do not need to literally map a source domain to a target domain. It is natural and inevitable for errors to be committed. This is because there are always

mismatches between the two domains for the simple reason that the two can never be correspondent in every way. Otherwise, they would not be two separate things but a single and identical entity. Although the computer can hold a conversation like a person, it does not harbor the physical abilities of a person, nor can it express emotion as a human being can.

5.1.2 Roles and Benefits of Metaphor in the User Interface

The primary role of the metaphor in the user interface is to help the users understand and form a concept of a system by utlizing their knowledge of familiar, concrete objects. By evoking in our mind a connection between a new computer system and the things that we have already experienced with the real world or with prior computer systems, the metaphor helps us understand the model of the new system more intuitively and naturally (Carroll and Mack 1985; Heckel 1991).

The user interface metaphor has been used in numerous computer systems. The first use of a metaphor was in Xerox Star (Bewley et al. 1983). Xerox Star used the office desk as a cognitive and visual framework. The basic idea was to organize data objects in a way parallel to how people organize their real-life office desks. After Xerox Star, Apple Macintosh and Microsoft Windows followed the desktop metaphor such that "familiar metaphors provide an intuitive interface to user tasks." (Apple Computer Inc. 1992; Microsoft Corp. 1995). Besides the desktop metaphor, many other metaphors have been used in GUIs—ranging from the simplest elements of the GUI (e.g. button, radio buttons, checkbox, menu, and tab) to very complex elements such as applications. A couple of well known application examples include Spreadsheet (physical accounting ledger), form fill-ins (paper-based forms), digital camera software (photo album), 3D virtual environments (the physical world), Internet browsers (navigation), email systems (interoffice system), on-line shopping (market), music/video players with Play, FF, REW, and Pause symbols (electronics).

Metaphors often come from real world objects, including many of the examples described above. Some scholars recommend real world metaphors (Brockerhoff 2000; Erickson 1990; Galitz 1997; Mandel 1997; Madsen 1994). This is because it is natural for people to correlate computer activity with its real-life counterpart. An example would be online shopping, many facets of which parallel the actual experience. Even if digital activities on the computer are not exactly mirror images of corresponding real world activities, they naturally tend to mimic some facets of the real world task semantics. In addition, according to Lakoff and Johnson's contemporary theory (Lakoff and Johnson 1980), when people are faced with a new situation or environment, it is common for them to try to relate it to something they already know or have experienced. In the same way, when people try to do some kind of digital activity on the computer screen for the first time, any familiar concepts from the real world can help them get acclimated.

Since the early days of the GUI, the importance of metaphor in the design of the user interface has been stressed and recommended wherever possible (Carroll et al. 1988; Faulkner 1998; Weinschenk et al. 1997). Carroll et al. (Carroll et al. 1988) argue that one of the key issues in a system design is to relate the system to the users' models based on the users' prior experience with other systems and aspects of ordinary life. Scholars such as Fineman (2004) claim that the use of metaphor is not merely an option in a GUI, but a requirement.

The primary benefit of the metaphor in the user interface is that abstract, unfamiliar concepts are understood in terms of concrete, familiar things. This helps users understand the underlying conceptual model of abstract, unfamiliar concepts. At the same time, a good metaphor makes it much easier to anticipate how interface actions affect the system.

Thus, a well-designed metaphor facilitates learning and the use of a new system. For example, when people confront a new media player system, if they have already experienced other media player systems, they probably first compare the new media

player system with them. If not, they would probably relate the new system to a media player device that they have used in the real world. They will also be able to figure out any new functionalities of the media player in comparison with the physical player. This will help them understand the concept and features of a new media player system. Carroll and Thomas (1982) found that familiarity of the metaphors influenced the level of satisfaction users had when they used a system for the first time.

The use of metaphor can also facilitate the design of a user-centered system. The user interface is usually influenced by the particular functionalities of the system, which in turn are determined by the system's internal structure. For instance, existing tools of the home network require that the user interface directly expose the internal structure of the network to users. To use such tools, users have to understand the terminologies, architectures, and functionalities of the internal structure of the home network. The use of metaphors, however, can allow users to interact with the system in a familiar way while it hides the home network's internal structure (unless there is some explicit reason why the home network's internal structure needs to be exposed to the user.).

The use of metaphor helps designers to maintain consistency in the user interface by asking the designers to keep in their minds a coherent metaphor. In addition, the metaphor can provide interface designers with new and different perspectives of design that veer from the original course but nonetheless have a synergistic result (Madsen 2000; Fineman 2004). Schon (Schon 1979) gives an example of the paintbrush-as-pump metaphor, which brings the paintbrush and the pump together, creating a new type of paintbrush with the perspective of the pump (the pump facilitates the flow of paint).

5.1.3 Drawbacks of Misused Metaphors

As discussed above, metaphors reach into our knowledge of familiar, concrete objects to facilitate the understanding of abstract computer and task concepts. At the

other end of the spectrum, however, poorly designed metaphors can sometimes lead to more confusion for the users, thereby subverting the designer's original intent.

Inappropriate metaphors can mislead users if there is an unacceptable amount of mismatching between a source and target domain. Therefore, designers of a user interface should identify any mismatches and find solutions for them. Some studies claim that mismatches are not necessarily counterproductive (Neale and Carroll 1997; Fineman 2004). If mismatches are properly corrected, they can allow designers more opportunity to fashion new and innovative functional and behavioral features of a system and allow users to explore those new features. There are magical features that are not doable in the real world but possible in the digital world. For instance, automatic sorting is not available in when doing a calculation in the real world, but it is a magic feature in the computer.

Inappropriate metaphors can also overburden users with too literal, unnecessary, or functionally irrelevant details (MacLean et al. 1991). The idea of a metaphor is to capture the essence of a meaning, task, or functionality of a source domain rather than simply simulating the source domain. Consequently, a metaphor that is too literal can be cumbersome to use because it does not always effectively or efficiently graphically represent in visual objects all the entities of a metaphor borrowed from the real world. For instance, if a desktop metaphor is used, it may not have to include an office desk unless it conveys a specific function. Microsoft's "Bob" is another good example of a metaphor that uses graphical representation that many consider to be too much or too "heavy." Bob was originally designed to provide a more user-friendly, nontechnical interface to desktop computing operations for Windows 3.1, but has become widely regarded as one of Microsoft's product failures. Bob used too extreme of visual representations; it included many functionally irrelevant decorative objects such as a fireplace and a sofa. In addition, Rover, a canine office assistant who uninvitingly popped up on the screen, was generally considered to be more irritating than helpful. On the other

hand, there were those that did not criticize Bob. Bob was a pure departure from the menu-based, text-intensive interface of Windows; it was a true task-oriented application instead of being program-oriented, something that had never before been seen.

In addition, metaphors can be too limited or too powerful, thus restricting the possibilities of the interface or representing entities that the system simply cannot replicate. Some scholars such as A. Cooper (Cooper 1995) have argued that metaphor is not helpful, but actually harmful since relying on real world or existing experiences can prevent designers from creating new functional or interactional features of a system. Instead, Cooper has proposed idiomatic design as the alternative to metaphors, which emphasizes "learning" how to accomplish goals (Cooper 1995). The basic argument of idiomatic design is that people can learn things, and once they learn things, they are able to remember and use them; hence, designers do not need to stick to things that are already familiar to people but can innovate new things. Unlike with metaphoric design, people do not need to rely on intuition or inference with idiomatic designs. He argues that many user interface features are actually idioms. Examples include checkboxes, radio buttons, push buttons, close boxes, and pull-down menus, although such idioms can be considered as primitive user interface metaphors as well.

Finally, metaphors contain the possibility of cultural limitations. One metaphor may fit well with some cultures while not fitting at all with other cultures. For example, the online shopping use of a shopping cart and a checkout process may not be understood in countries in which bartering is the only way to get things. Similarly, the connotations that come with color can vary from culture to culture and may lead to confusion when they are used in a user interface.

5.1.4 Why Metaphor for the Home Network Management Domain

The use of metaphor can have prominent effects on home network management. For most residential users, the conceptual model of the home network (even networking

itself) is unfamiliar and not easily imaginable. It includes many computational/networking concepts such as device provision, access rights, resource allocation, and a logical network topology. If, however, the model employs concrete, familiar concepts from the real world, users can more easily acquire a better understanding of the concepts and the overall operation of the network, thereby increasing the usability of the home network for general household use.

The concept of adding or removing devices for membership management is an invisible, logical concept. Such device configuration concepts can be unfamiliar if users do not have technical knowledge of networking. They may not even recognize that doing configuration is a necessary part of membership management. For most residential users, a more concrete concept for adding or removing devices might be the concept of the home network as a physical space. Using this model, users could easily understand the idea of placing a device inside or outside the physical space. Their mental model on membership management would be strongly associated with the physical placing of devices inside or outside the physical space of the home network. In this way, the metaphor of the network as a "space" can effectively communicate the complexity of device configurations as a simple matter of adding devices to or removing them from the space.

Basic residential users also do not have really fully understood how the home network works as a distributed system. With a concrete metaphor (e.g. a link-pipe in Eden), they will be able to sufficiently grasp the operational model of the home network.

When users are already very confident with the domain of the home network and know what it can do for them and how to use it, the interface metaphor may not have the expected profound effects the effort of cognitive mediation between such users and the home network is not so demanding. However, the interface metaphor has the potential to significantly help users with little technical knowledge of networking achieve their management goals in a manner that they are familiar with.

5.2 Eden User Interface Metaphors

Eden employs several user interface metaphors. For an overall visual and behavioral model, Eden uses a spatial metaphor in the form of a Home and a relational and network data transfer metaphor in the form of a link-pipe. For tasks, it utilizes several types of metaphors. In the rest of this section, I will describe these metaphors in detail as spatial metaphors, hierarchical relationship metaphors, and task metaphors.

5.2.1 House: a Spatial Metaphor to Represent the Home Network

A spatial metaphor maps spaces for abstract computational domains. It makes use of the human ability to use physical space to organize objects and to make logical deductions about their locations (Kuhn and Blumenthal 1996). A spatial metaphor can utilize various structural aspects of spatiality in the real world to convey abstract information. For instance, it can exploit the center and periphery of a space in order to convey the relative degree of importance or focus of objects within that space. People often place more important objects in the center and less important ones in the periphery. Similarly, they often place objects of current focus in the center and ones of out-of-focuses in the periphery. Another example of structural aspects of spatiality that the spatial metaphor exploits to convey abstract information is a container structure. People put objects which satisfy some constraints inside a spatial container while leaving objects that do not satisfy these constraints outside the spatial container. In addition to structural aspects of spatiality, a spatial metaphor utilizes natural strategies for orientation and navigation in the real world in the forms of maps, buildings, or cities.

Spatial user interface metaphors have been used in many GUIs for information visualization, information navigation, and GIS. For example, Dieberger (1997) used the city as metaphor for navigation, and Second life uses the metaphor of a world.

Eden employs a spatial metaphor, especially one utilizing the structural aspects of spatiality in the real world. The most typical way to present the home network is by using

a tree map representation, which best expresses the logical topology of the home network. In addition to the tree representation, Eden utilizes the reasoning of the locations of objects in a residential space (a house) to represent the abstract concepts of networking.

There are three reasons that Eden uses the spatial metaphor of a house. First, spatial metaphors address the thoughts of users about the home network revealed in early studies (Poole et al. 2008; my formative study). Many intermediate and novice users view the home network within the spatial architectures of their own homes. They think of the home network as having physical devices and the actual locations of these devices within their homes. As a result, the spatial metaphor can provide natural mapping between users' thoughts about the home network and their visual representation of the home network.

The second reason Eden uses a spatial metaphor is that this provides opportunities for users to utilize the conceptual structures of the space mentioned above. For instance, Eden uses a conceptual structure, a container, to represent the affiliation of devices to the home network. This container structure is very common in GUIs. The desktop metaphor is based on a container structure, in which windows and folders not only take spaces on a screen, but also "contain" objects "inside" them.

The third reason for using the spatial metaphor in Eden is that it provides opportunities for designers to integrate the social aspects of the household, which can then affect the way that the user sets up the home network. For example, parents often want to restrict access to network resources (e.g. the Internet) in a child's bedroom computer (Poole et al. 2008). They may forbid their children to access the Internet when the children are by themselves. However, they may allow their children to access the Internet through a family computer in public spaces such as a living room under parental supervision. In this case, the child's bedroom is considered as a space in which the Internet access is forbidden. In this way, spaces can be endowed with some meaning by behavioral frames or social meanings of households. Harrison and Dourish (Harrison and

Dourish 1996) called such space “place”. They argue that a place has social meaning and that this meaning is determined by the practices and understandings of communities.

The rest of the section describes the details of the Eden Home metaphor.

Home The physical Home maps into the home network, an abstract, invisible object. The physical boundary of the Home distinguishes between networking objects in the home network and those outside the home network (i.e. on the Internet). The Home provides natural mappings so that the user can more easily see whether networking devices are on the home network or not. The membership of a client device, the device is in the home network directly maps into that the graphical icon of the device inside the House.

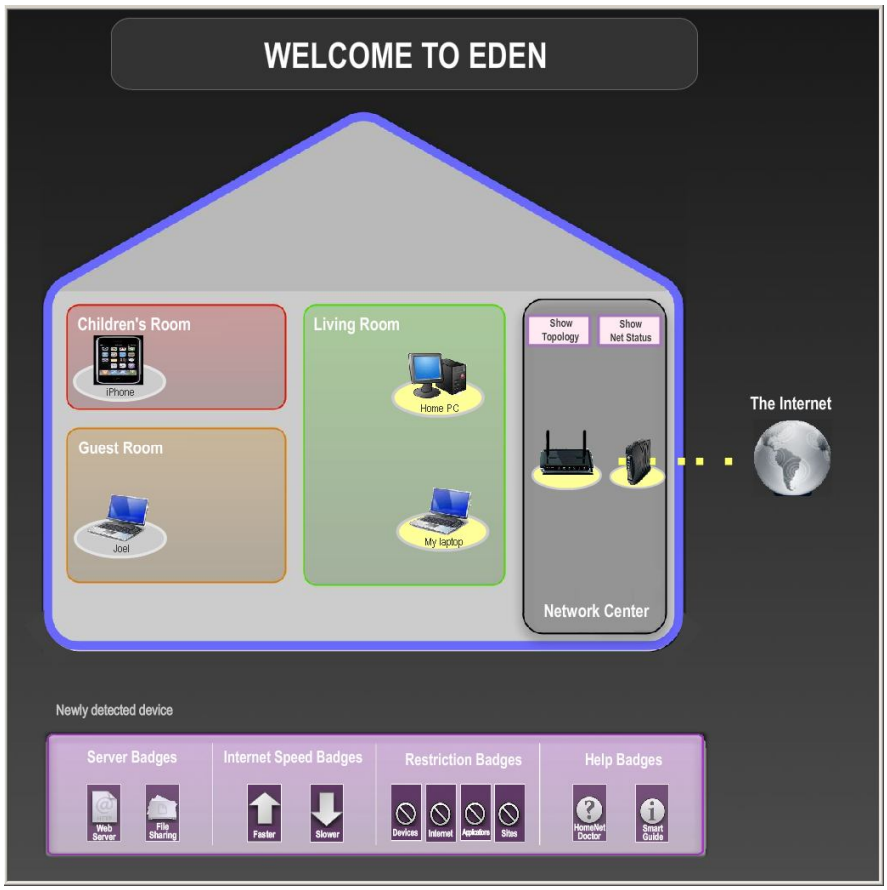


Figure 17: House, a spatial metaphor to represent the home network

The Home contains sub-containers, Network Center, Rooms, and Newly Detected Device Area, each of which has its own particular associated meanings.

Network Center Network Center is where core networking devices such as a modem or a home gateway router are located. Network Center mimics the physical location of the modem and a router. In the real world, a modem and a home gateway router are usually right next to a wall, plugged into an Internet service jack. A wall is often seen in sketches of users about their home networks both in previous research (Poole et al. 2008) and my formative study.

Room The Room is where client devices in the home network are located. It respects the spatial architecture of the physical house. Users can add, arrange, and name rooms according to the physical structures of their real houses. The Room, however, has a breakdown when client devices are mobile devices. In the real world, mobile devices keep changing their locations within the house. However, the objects for client devices in Eden do not automatically update their locations. Updates occur only if users manually perform them. There are several ways for users to work around this weakness of Eden. One way is for users to place mobile devices in the Home based on the ownership of the devices because users often label devices according to ownership (e.g. Bob's laptop). Bob's laptop, for instance, is placed in Bob's Room. Another user strategy could be to place mobile devices in the Home based on the locations within the Home in which they are most frequently used. For instance, a user could designate the Couch in the Living Room as his/her laptop's habitat in his/her drawing of the home network (Poole et al. 2008).

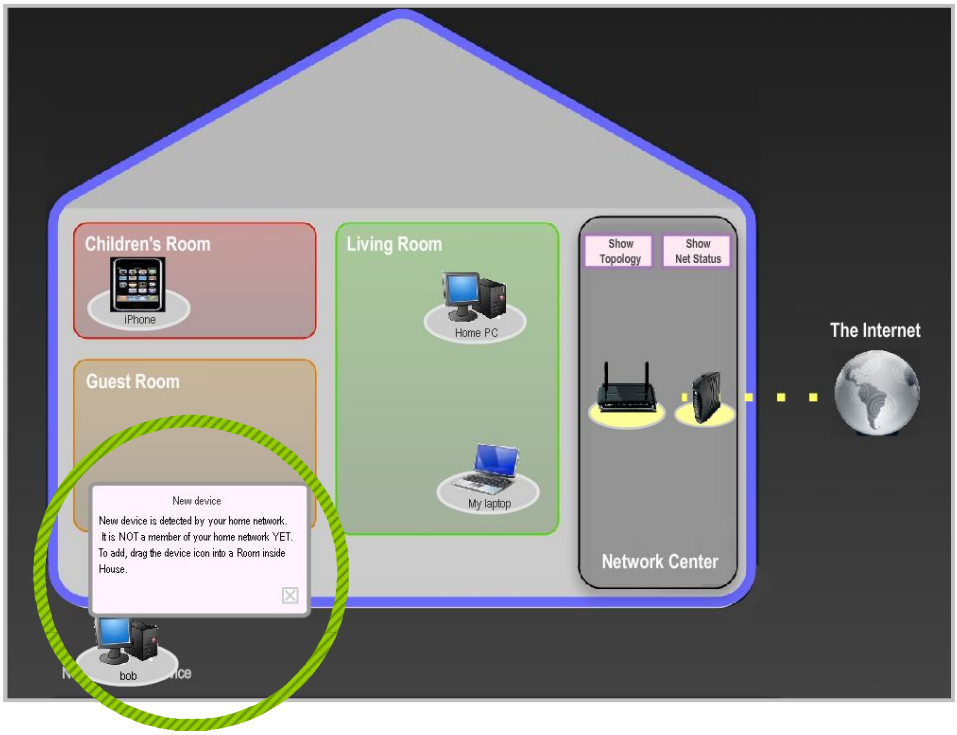
In addition to providing physical mapping of client devices, the Room represents a place. It mimics the social meanings of households in the real world. As a room frames the behaviors of householders in the real world (e.g. living room, study room), the Room frames the behaviors of client devices. For instance, different users – a child, an adult, a visitor – may have different access rights for devices in the home network and different

Internet access. Devices in each Room – the child's room, my room, the guest room in Figure 17 - are endowed with different access rights according to owner of the Room.

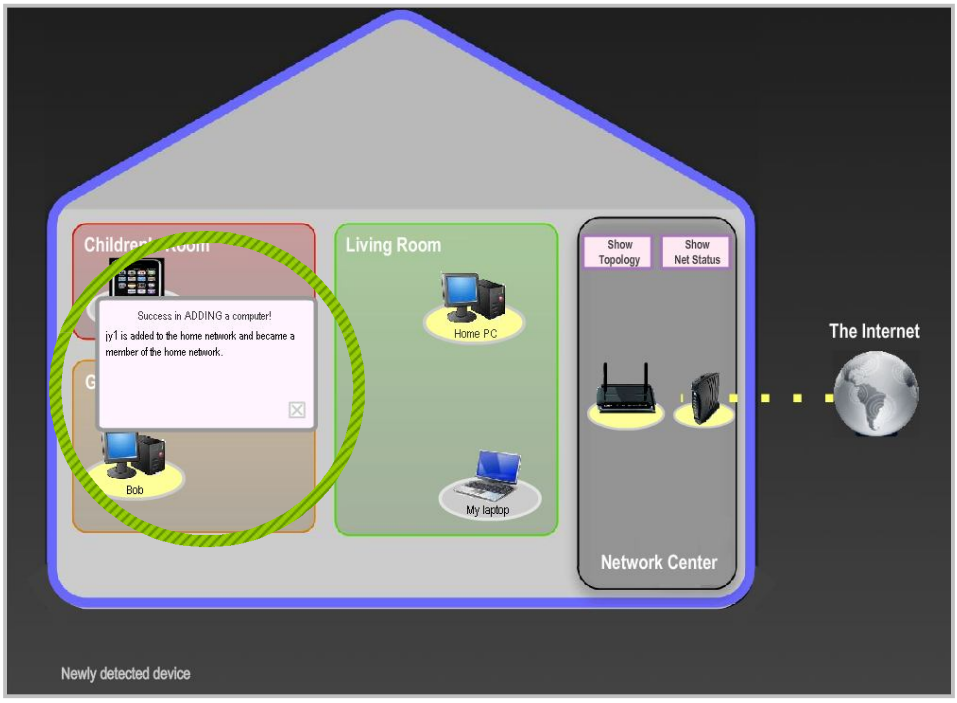
Newly Detected Device Area Newly Detected Device Area is where a device newly detected by the home network is located. Users can drag it into the Home or outside of the Home to control its membership to the home network. If users drag it into the House, the device becomes a member of the home network. If users drag it outside the House, the device cannot be a member of the home network and disappears from the screen. Although devices in Newly Detected Device Area are physically (through either a wired medium or a wireless medium) detected by the home network, they are prohibited from access to any home network resource. This has the same effect as not being connected to the home network all.

Users can change the membership of client devices by dragging them into or out of the Home across the physical borderline between the body of the Home and the Newly Detected Device Area (Figure 18 and Figure 19). Once the device is placed inside the House, users can see the detail information of the device and change the device icon by double-clicking the device (Figure 20). Users can also change the name of the device by editing the device name field below the device icon.

Only client devices are movable. Other networking objects such as the router, the cable modem, the ISP, or Internet are not movable because their affiliation is not changeable. This will prevent users from making errors such as dragging an ISP into the House. When users try to move a networking object, they will get a mini notice dialog box saying that they cannot move the object because its affiliation is fixed.



(a) A newly detected device appears in the Newly Detected Device Area



(b) A device is placed inside the Home and connected to the home network

Figure 18: Adding a device to the home network by dragging it inside the Home

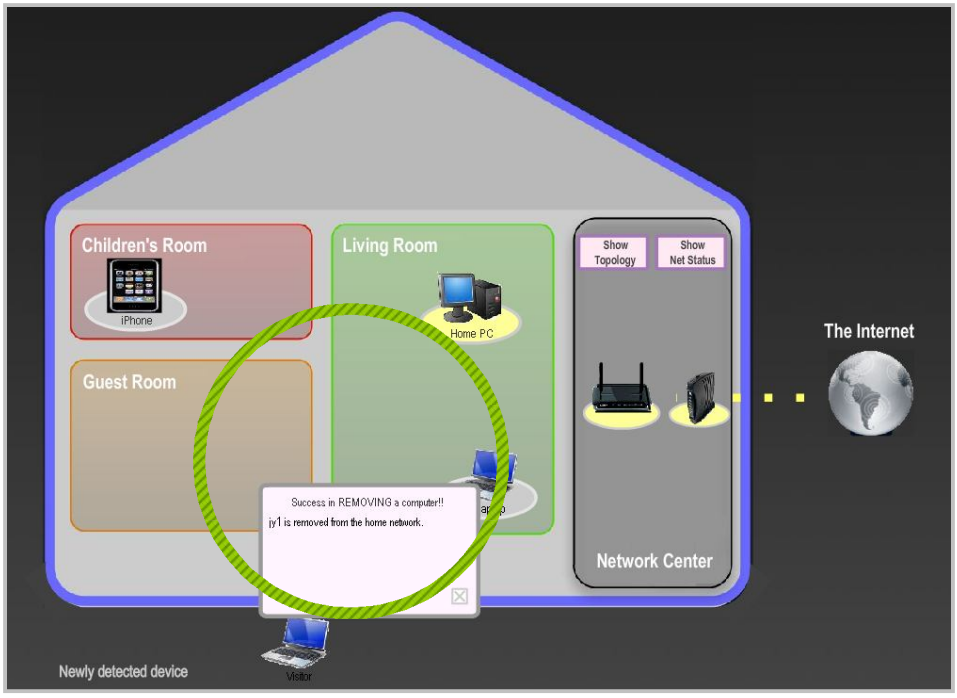


Figure 19: Removing a device from the home network by dragging it outside the Home

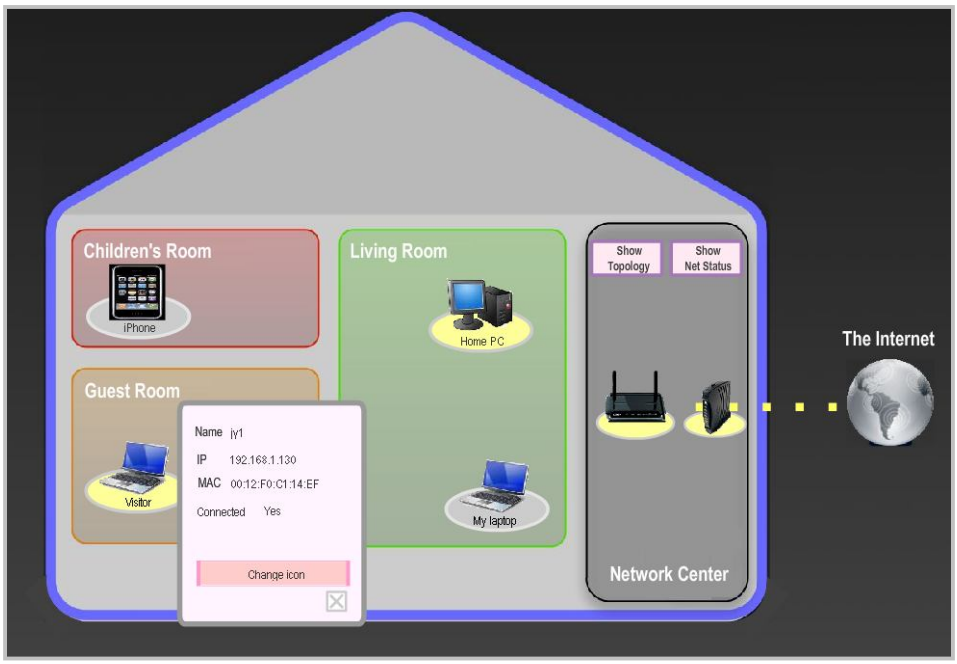


Figure 20: Seeing the details of the device and changing the device icon

5.2.2 Link-Pipe: a metaphor to present the logical network topology and network traffic flow

Eden uses a link-pipe metaphor to represent the logical network topology of the home network and network data flow, respectively.

The link visualizes the logical network topology of the home network as it does in the traditional network tree map. In the real world, the link tells some relationships between two objects. The link in Eden represents the logical connection relationship among hardware components in the home network.

In the real world, a physical pipe is a tubular conveyance that carries fluid between two stations. In the same way, the pipe in Eden conveys abstract network data traffic between two nodes. Network data traffic is represented as a dot (a chunk of bytes). The density of dots indicates the amount of network traffic per unit time. Eden also provides an option for more detailed revelation of network data traffic. Instead of a dot regardless of network data traffic types, the icons of application types can be used to specify the types of network data traffic. In this case, privacy could be a concern because users may not want even other family members to be able to see what applications they use.

Pipes are established between two nodes that are logically connected with each other. By observing the structure of the pipes, users will be able to tell which path network data is transferred along.

The pipe metaphor of Eden has a breakdown. Network data traffic is bi-directional – incoming and outgoing. On the contrary, a pipe is uni-directional at one moment. To resolve this breakdown, Eden could have used two separate pipes for incoming and outgoing network traffic. However, Eden uses a uni-directional pipe because distinguishing incoming and outgoing network traffic may not be meaningful at an application level. Referring to incoming and outgoing network traffic would be

redundant in terms of network traffic types (i.e. applications). That is, if users visit a web site, the outgoing network traffic will be an HTTP request sent to the web site (server), and the incoming network traffic will be an HTTP response with the web site contents. Both incoming and outgoing traffics are the same web application type.

Users can enable or disable two options, “Show Topology” and “Show Net Status”, that show the topology and traffic flow (Figure 21, Figure 22, and Figure 23). If users enable the “Show Topology” option, Eden shows the hierarchical network topology among the router and client devices. If users enable the “Show Net Status” option, Eden shows the network traffic flow of the home network with the network speed of each device and the router. It also shows the network applications that are running on each client device.

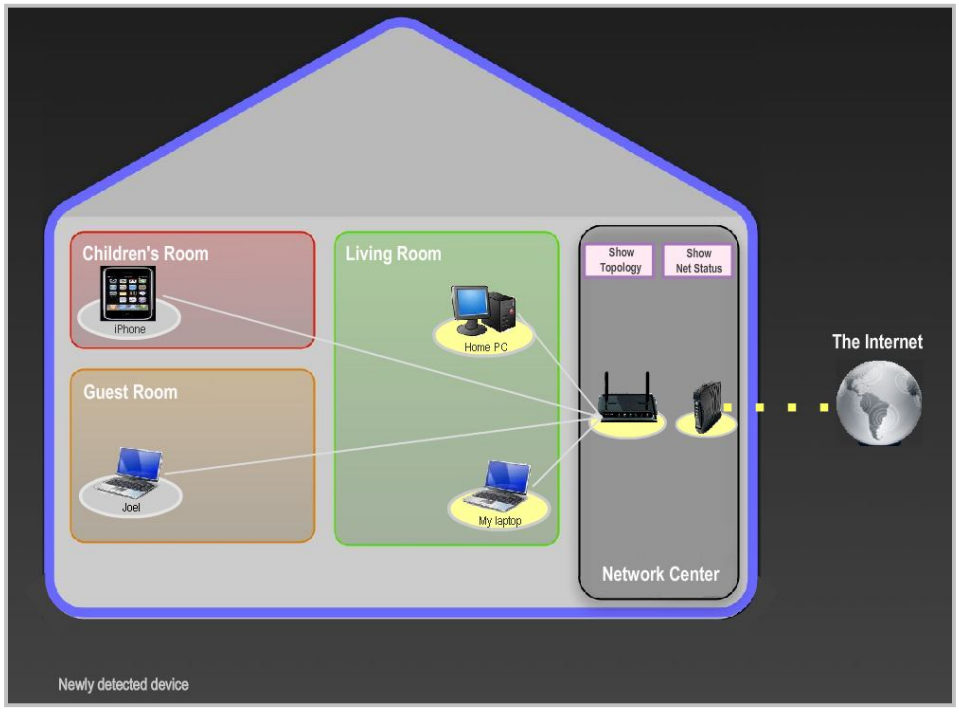


Figure 21: Enabling the “Show Topology” option

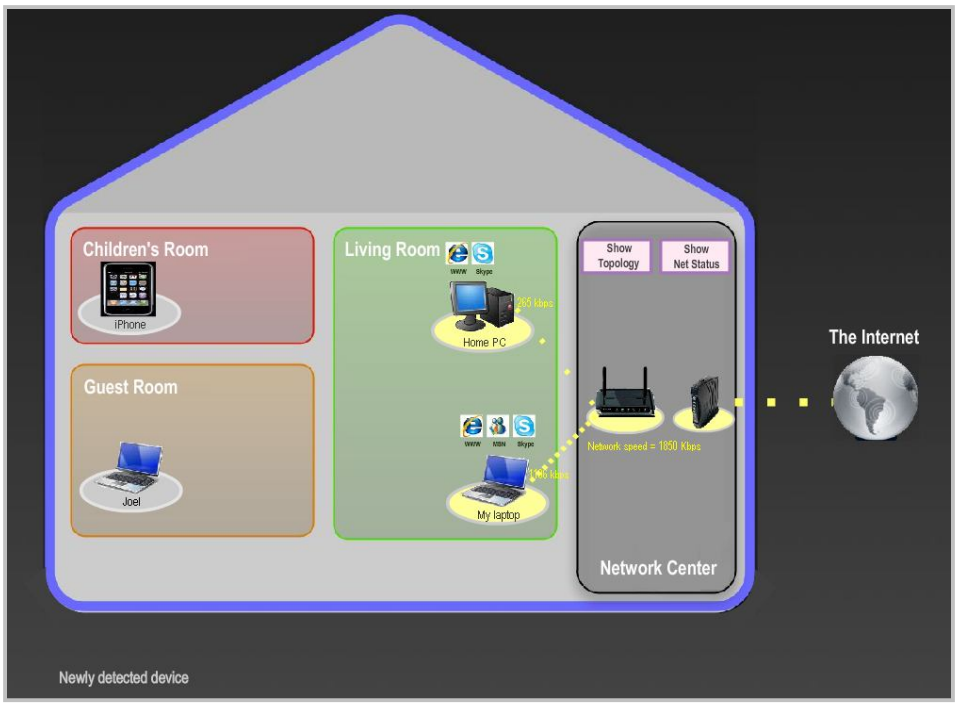


Figure 22: Enabling the "Show Net Status" option

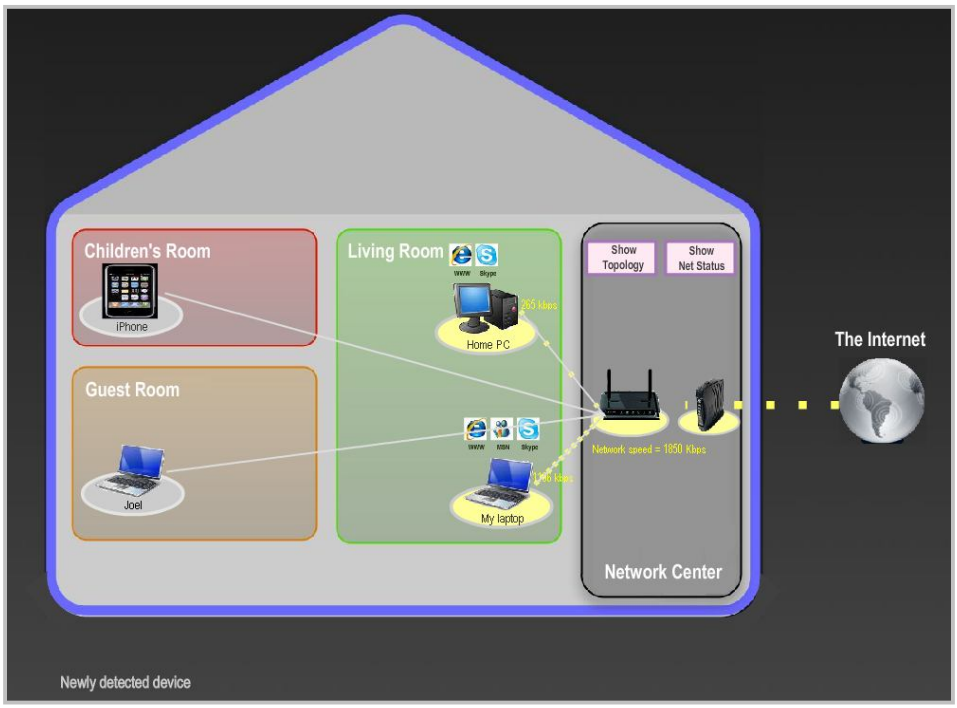


Figure 23: Enabling the "Show Topology" and "Show Net Status" options

5.2.3 Badge: a Metaphor to Represent Network Settings

Eden uses a badge metaphor for several network settings - server configuration, QoS control, and access rights. The badge provides at-a-glance awareness for network settings that are associated with client devices. In the real world, people place badges on objects to visualize or assign some properties for those objects. For instance, people place price badges (tags) on objects to specify the prices of those objects.

The badge metaphor converts abstract network properties into a concrete, familiar real world object. In addition, the badge metaphor allows users to better grasp (understand) the concept of network settings and the way to activate the network settings for their client devices. The badge metaphor also provides good affordances for network settings, which would otherwise be hidden.

The number of badges for each network setting depends on the number of network settings. For instance, there is only one instance of a server badge, WEB server or FTP server because the network can have only one port 80 WEB server or one port 21 FTP server at a time. This is because port forwarding can be set up to go to only one host at a time, so the standard port 80 for HTTP, for instance, can go to only one web server host on the network. If the network wants to host multiple web servers, it has to set up port forwarding to work on non-standard HTTP ports.

In theory, Internet speed badges or access rights badges could have infinite number of instances. Internet speed badges are implemented by “tc”, which is a tool that shapes network traffic. Traffic shaping rules are determined by the user, who can choose what kind of traffic and how much of it should be allowed on/within the home network. For example, users can apply the highest priority for bandwidth usage to network traffic related to a specific client device or a group of client devices. Then all other client devices will become secondary to the needs of the client device(s) with the highest priority. Access rights badges are implemented by “iptables”, which decides whether to

drop or pass specific network traffic based on the pair of source-destination IP addresses and port numbers.

The concept of badge in the user interface has proved to be an easy-to-understand and intuitive use interface for privacy settings for small mobile devices in ubiquitous and pervasive computing environments (Gisch et al. 2007).

By default, Eden places no access control on the network other than the access control implicit in membership management. When users want to do some access control, they use corresponding badges. For instance, when a user wants to block all Internet access to a child's device, the user attaches a "Block Internet" badge to the child's device or the Room in which the child's device is placed. This action prohibits the child's device from sending any network data outside the home network or receiving any network data from the Internet. On the other hand, if a user wants to control only some websites or some applications, the user places a "Block Sites" badge or a "Block Applications" badge on the device or the Room in which the device is placed. Then a "Block Sites" badge and an "Block Applications" badge pulls down and asks the user to input the specific URLs or applications to be blocked. A "Block Sites" badge prohibits users from browsing the specified URLs. A "Block Applications" badge blocks all network traffic for the network ports corresponding to the specified applications. Users can still run the applications; however, the applications will not work. When a user wants to block access to devices on the local network for all visitors at one time, the user can place " Block Devices" badges either on every individual visitor device or on the guest room. Devices with a "Block Devices" badge may see other devices in the local network, but they are not allowed to access those devices.

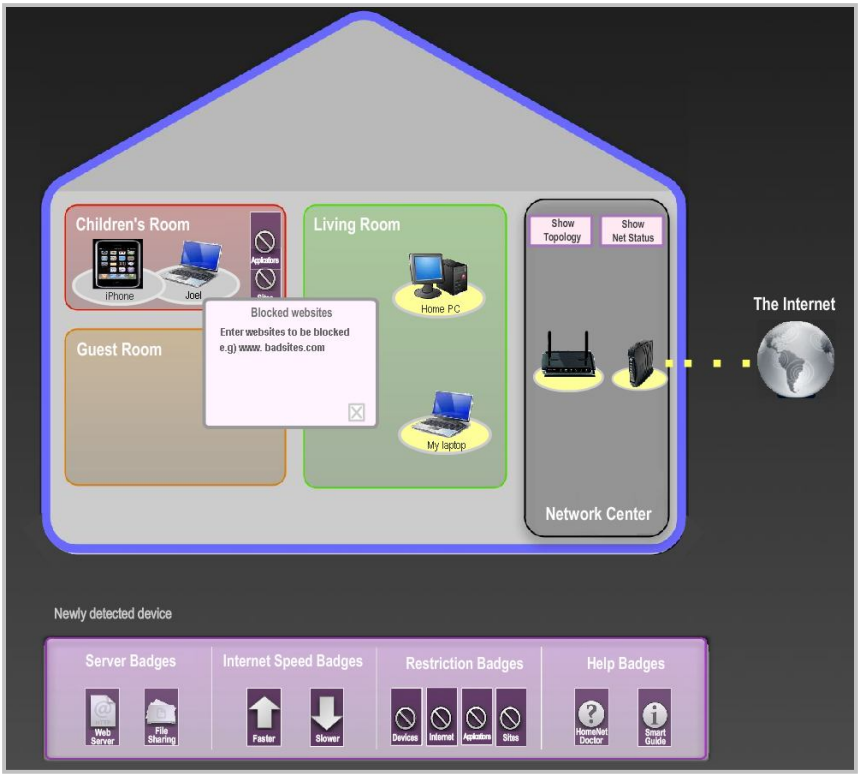


Figure 24: Placing a "Sites" badge on the Children's Room to block Children's devices

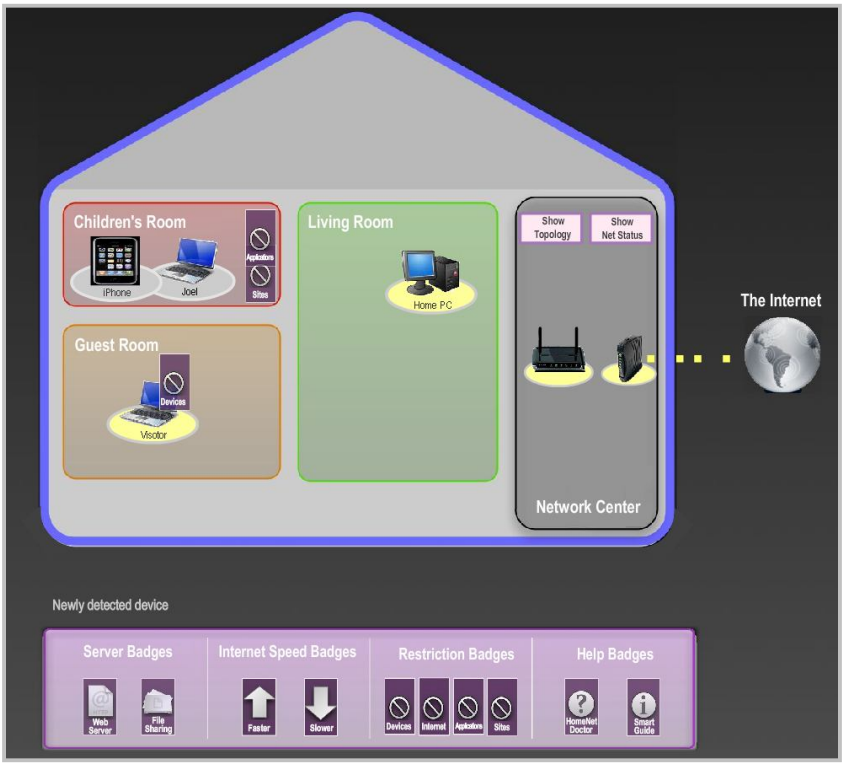


Figure 25: Placing a "Devices" badge on a visitor's device

In the same way, if a user wants to assign a specific device or application a high priority, the user places a "Faster" badge on that device as shown in Figure 26.

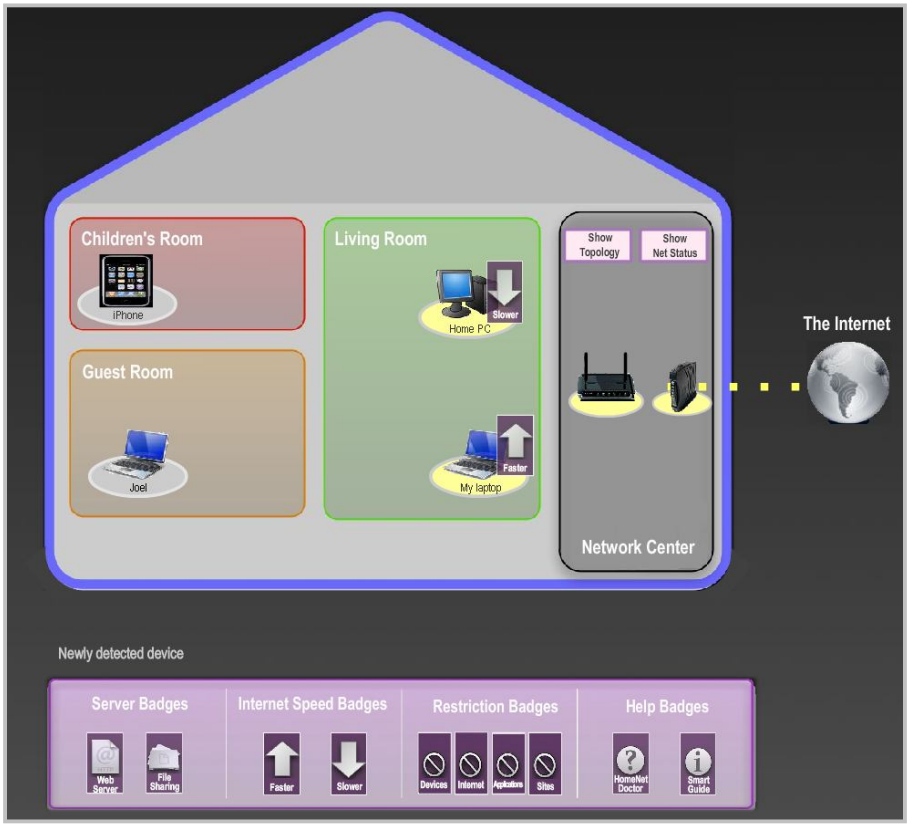


Figure 26: Placing QoS control badges on devices

If a user wants to make a specific device (such as a web server or a media file server) accessible outside the home network, the user puts a "Web Server" or "File Sharing" badge on the device.

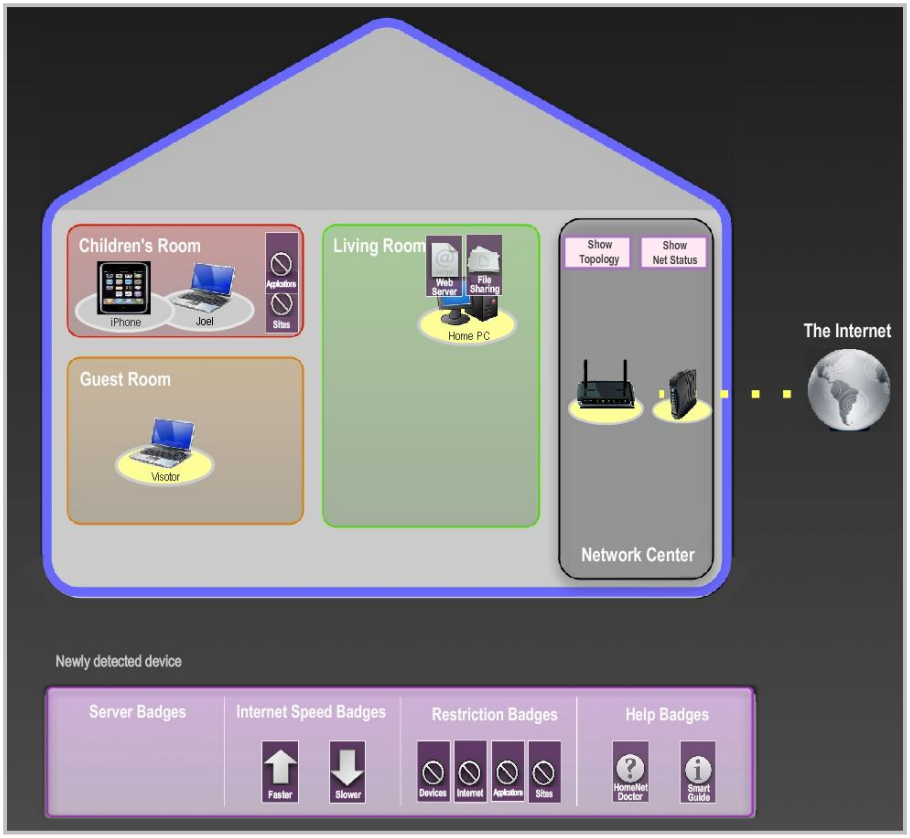


Figure 27: Placing "Web Server" and "File Sharing" badges on a device

The badge provides three control levels – individual, group, and network - as shown in Figure 28. When a user puts a badge on a specific device, only that device is controlled. When a user puts a badge on a Room, all the devices in that Room are controlled. When a user places a badge on the Router, all the devices in the home network is controlled.

Such different granularity of the control levels allows users to do access control more efficiently for different cases. For instance, if users want to block p2p applications coming through the home network for all computers in the home, they just place a "Block Applications" badge on a router instead of placing the same badges on individual devices mulitple times. If users want to block visitors from devices on the local network , users place a "Block Devices" badge on the guest Room once. Then, when they have visitors' devices in later, they just place the visitors' devices inside the guest Room. They do not need to place the same badge on all the visitors' devices every single time they have visitor devices.

The use of the Room as a spacial metaphor functions well to communicate the idea of what kind of - or area of - access is being controlled. Not only does the Room provide physical mappings for devices, but it also integrates the social aspects of the household as a "place", one endowed with some meaning of households as in the above example of the guest room for all visitor's devices.

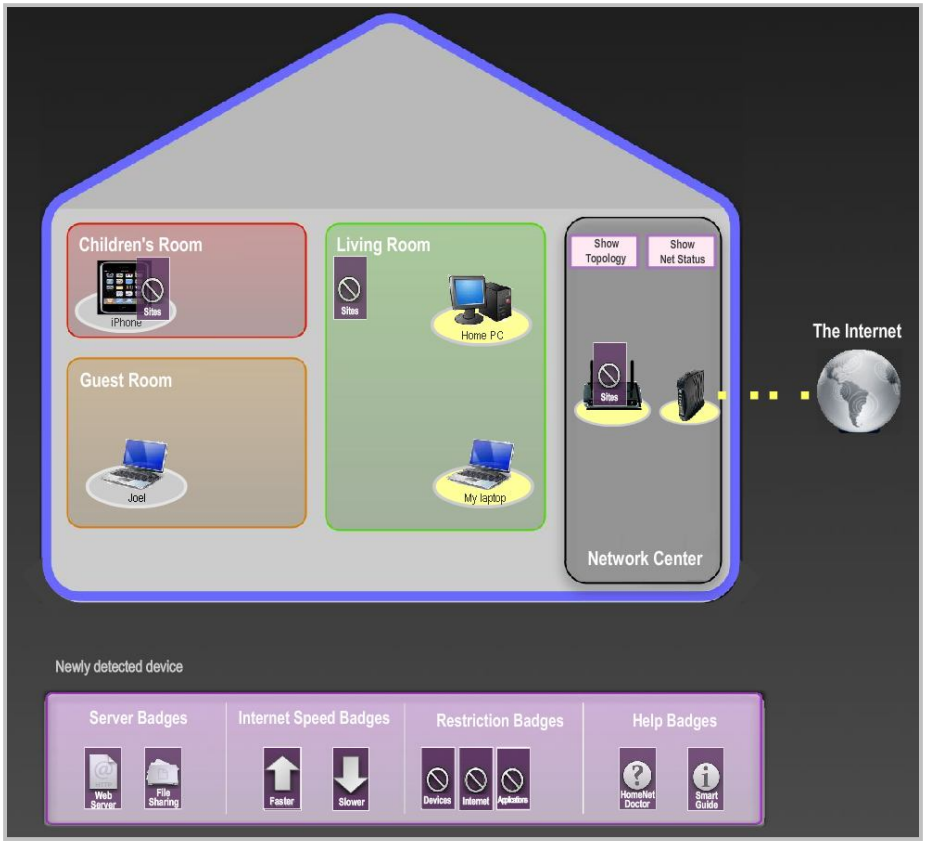


Figure 28: Placing badges at the three different control levels

5.2.4 Assistant: a Metaphor for Help

A manual and troubleshooting is an assistive management area in which users can find help for something that they do not know. Eden takes an assistant metaphor for a manual and troubleshooting. In the real world, when people do not know how to use a certain object or what is wrong about the object, they ask someone who knows better than themselves about the object. Eden takes advantage of the same analogy for the assistive management area.

Smart Guide is a visual manual object. It helps users understand what network components of Eden are for and how to control them. When users do not know what components of Eden are for or how to control them, they ask Smart Guide. They bring Smart Guide onto target components, which means showing target components. Smart Guide will then tell what they are for and how to control them.

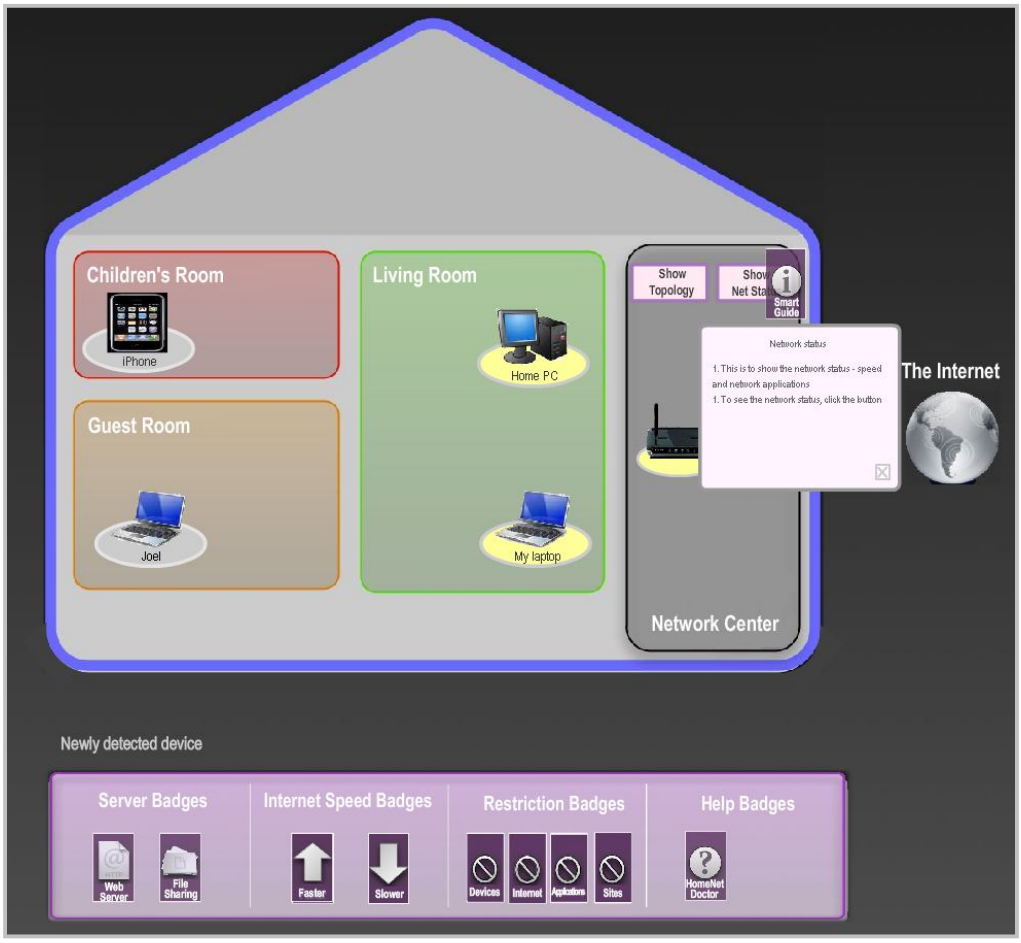


Figure 29: Placing Smart Guide on a "Show Net Status" option in order to determine what this option is for

Smart Guide has advantages over a traditional operating manual. Traditionally, the most common format that manuals have taken is an index-based or search-based textual form. This traditional form of help has drawbacks for home network management from the perspective of user interaction. Users with limited technical knowledge find it difficult to verbally articulate what they are looking for in technical words. To use traditional form of help methods, users have to have previous knowledge about management controls. A visual help object, such as Smart Guide, integrated into the visually represented world of the home network can minimize the drawbacks. Since the object can be brought directly to the place where help is necessary, it provides users with more engagement with help. A visual help object not only does not require to verbally request what they are looking for in technical terms, but it also allows users to explore what controls are available in visual components of the home network.

Currently, the help information that Smart Guide retrieves is built into the system. It is static help information. However, I envision that it will ultimately be able to provide more dynamic context-sensitive help based on the dynamic status of the home network.

Smart Guide has a metaphor breakdown. In the real world, the real helper that people ask for help with the home network could be more knowledgeable and intelligent than Smart Guide, especially given that the current implementation of Smart Guide is based on the static help information, not on the dynamic context-sensitive help information. Smart Guide is also not as interactive as the real helper. In the real world, users ask the helper, and if the answer from the helper is not clear or raises other related questions, users ask the helper again. However, Smart Guide can not support such iterations in interaction.

HomeNet Doctor is a troubleshooting assistant object. In the real world, when people have a health problem, they see a doctor and let the doctor diagnose the problem. In the same way, when users confront a network health problem, they let HomeNet Doctor take a look at (diagnose) it and provide potential solutions for that problem (Figure 30).

The approach of HomeNet Doctor has advantages over traditional troubleshooting methods. When users confront networking problems with some devices, they often do not know where to start or what tools they need to use. In Eden, HomeNet Doctor is where users can go when they confront networking problems. It allows users to tell the system what to check by directly pinpointing malfunctioning devices. In addition, HomeNet Dcotor provides an intuitive and consistent user interface regardless of the types of problems or problematic devices.

HomeNet Doctor has a similar breakdown as Smart Guide. HomeNet Doctor can not be as knowledgeable and intelligent as a real doctor. It uses just limited heuristic rules based on information collected via command line network diagnostic tools such as “ping”, “traceroute”, and “netstat.” It is also not as interactive as a real doctor. It provides only predefined network problem options and thus can not answer more detailed questions.

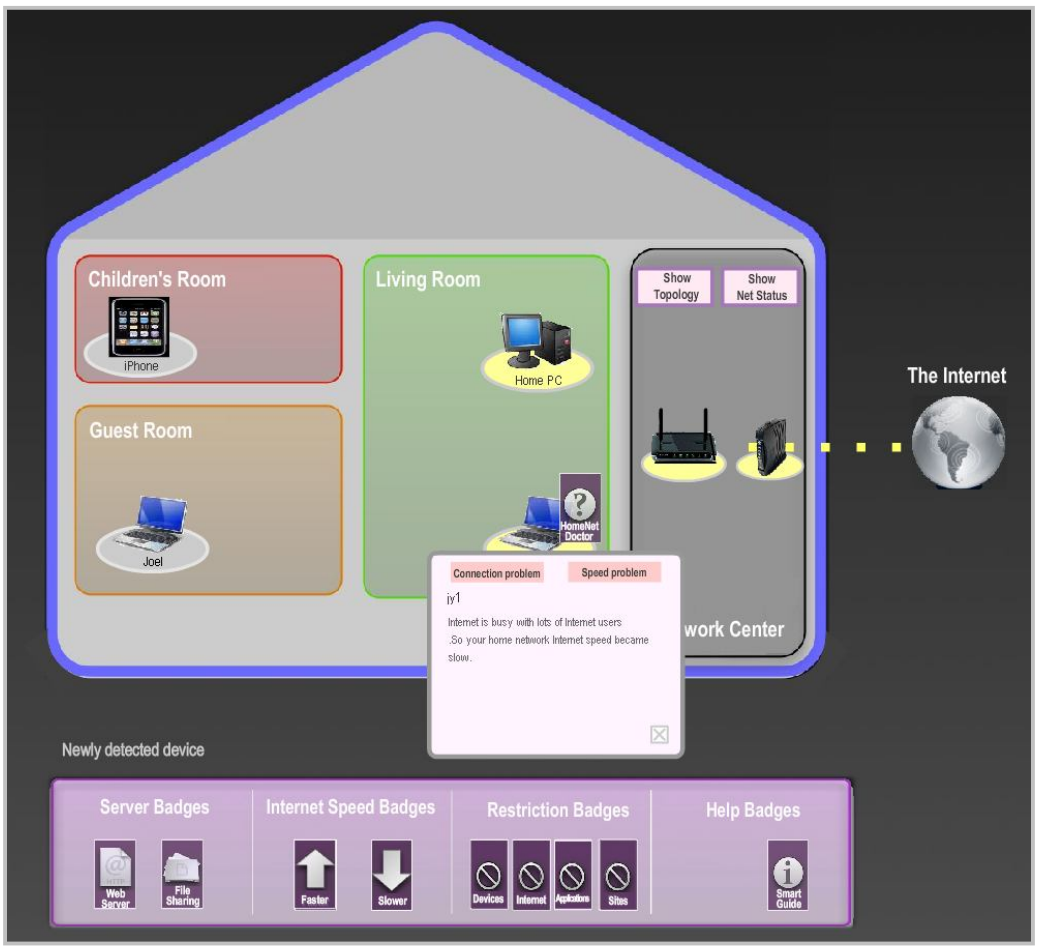


Figure 30: Placing HomeNet Doctor on a device to determine why this device's network speed is slow

CHAPTER 6

EDEN IMPLEMENTATION

6.1 Development Platform

We built a Linux wireless router with a desktop, and Eden runs on the Linux router. Eden does all the home network management work, and thus no changes are required in any home client devices. This makes Eden compatible with the current home network infrastructure. In addition, it can oversee the entire network with no extra overhead since the router already has all the network configuration and status information. In contrast, the PC-based tools (e.g. Network Magic) cannot get a full picture of the network without extra coordination overhead. To get a full picture of the network, the PC-based tools need to collect necessary information about devices other than the device that runs the tool from either the router or other devices. Any PC-based tools also require extra software installation on client devices.

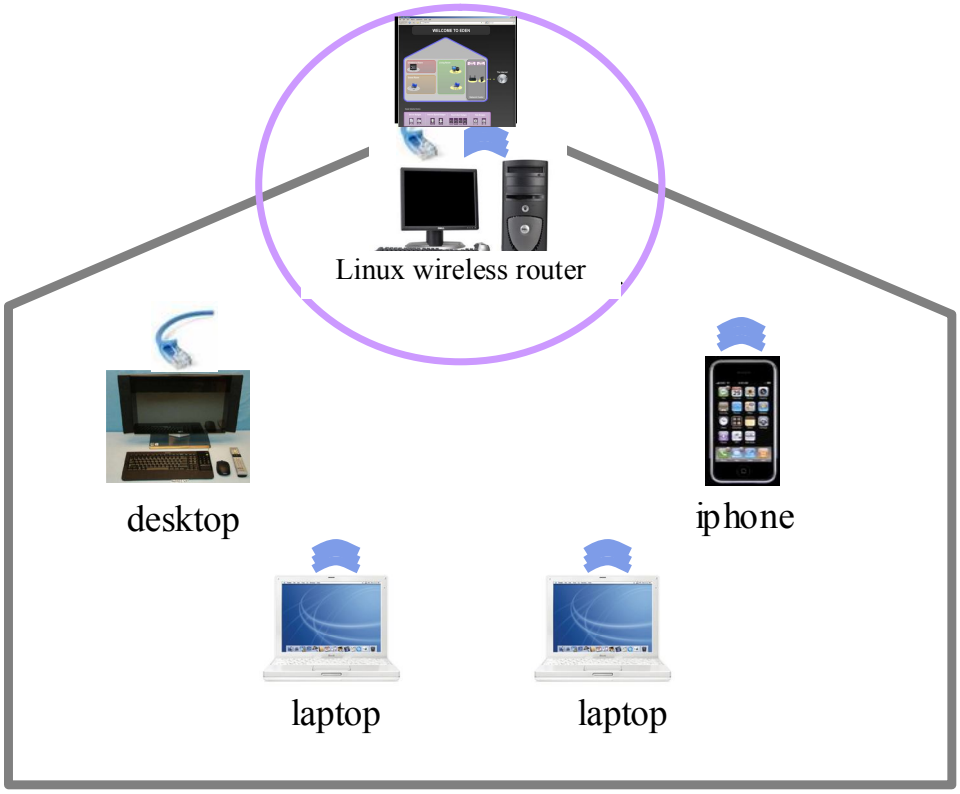


Figure 31: Eden's development platform

6.2 Web-based Management Environment

Eden operates in a web-based management environment. The web-based environment addresses several usability issues that users mentioned in the formative study. First, it allows universal access to the management system, which means that users can access the management system with any computing devices in the local network. It also requires no extra software installation on client devices. Further, users can easily get to the network management system by entering a designated URL, "eden", in a browser address bar. The URL is changeable by users. Lastly, Eden provides potentials as a remote, shared management environment for family members, friends, or external professionals.

In addition, the web-based management environment allows Eden to take a centralized management approach while still supporting universal access. The centralized approach has benefits from several perspectives. It is a simple architecture, requiring no extra work on the user's part to coordinate among devices participating in management. It also can reduce network traffic overhead and increase the user's chances for better network management. The gateway router, the top node in the network, monitors all incoming and outgoing network traffic sitting between the boundary of the Internet and the home network. Thus, it can oversee the entire home network. The centralized network management also respects the conceptual models that users have for the home network – a single designated place for network management. I expect that this aspect will be especially helpful to network users with little experience who think of the home network as a single big chunk of the backend network infrastructure. However, the web-based management environment requires that the network be working well enough so that it can contact the router.

6.3 System Architecture

Eden consists of a front-end user interface and a back-end network engine part. Figure 32 shows the system architecture of Eden.

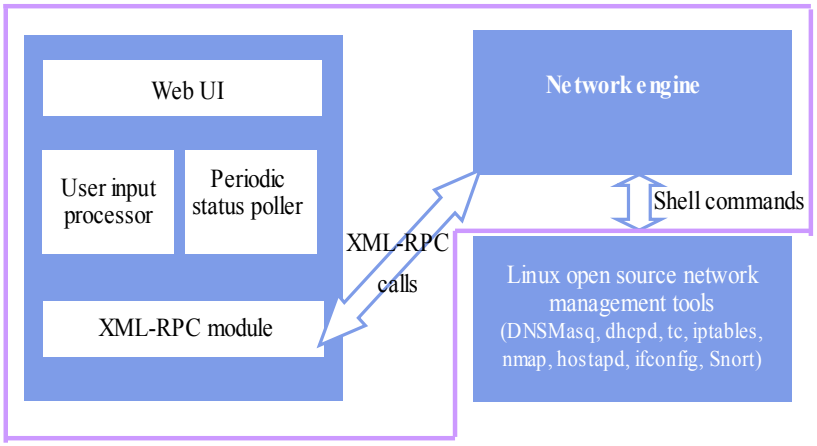


Figure 32: System architecture

The web-based user interface gets user input and provides output to users. The user input processor processes user input and, by using XML-RPC, sends corresponding network commands to the network engine, which then conveys those commands to the Linux router using shell commands. The periodic status poller pings the network engine every 5 seconds to check for any changes on the network by sending XML-RPC requests to the network engine to see if there are any updates in the home network. The network engine then sends any updates to the network engine polling module, which, in turn, updates the user interface if necessary. The network engine uses open source network management tools developed for Linux – "DNSMasq", "dhcpd", "tc", "iptables", "nmap", "hostapd", and "ipconfig" - for a set of network management tasks that it supports.

I chose XML-RPC because it provides a standard specification for communication between applications written in a wide variety of languages. XML-RPC allows for the writing of various client front ends that all hook into the same back-end engine. Such flexibility supports a variety of different UIs written in different languages

and placed in different parts of the architecture, both on a home gateway router and on individual computing devices connected to the home network.

The front-end user interface was written in Adobe Flash CS 9 and ActionScript 3.0, and is embedded in an HTML file. The network engine is written in the Ruby script language[12].

6.4 Task Implementation

6.4.1 Membership Management

For membership management, Eden allows users to add or remove a client device by dragging a device inside or outside the House. By default, the device waiting outside the Home is permitted no access, which has the same effect as the device not being connected to the home nework. Once the device is placed in a certain room in the House, the device is given access rights to the home network resources.

To implement manual configuration-free, drag-and-drop based membership management with the current infrastructure-mode (wireless) network, Eden manipulates IP addresses. The Newly Detected Device Area the Home and its Rooms are associated with a certain range of IP addresses, and the rule of access to the home network resources applies to the range of IP addresses. When a device is placed inside the Newly Detected Device Area, the device is assigned an IP address in the range of IP addresses of Newly Detected Device Area. The IP addresses of Newly Detected Device Area are blocked from all acccess to the home network. When the device is placed in a Room, the device is reassigned an IP address in the range of the IP addresses of that Room. Then the device is allowed access to the home network. Changing the location of a device from one Room to another changes the IP address of the device. Eden uses the same DHCP to assign

[12] http://www.ruby-lang.org/en/

addresses. However, to allow the illusion of changing a device's IP address, the DHCP lease is set up to be 2 minutes. In this way, devices are forced to ask Eden for a new address frequently enough so that it seems the address gets changed automatically.

6.4.2 Access Control

By default, Eden keeps the firewall enabled. Then, Eden creates port forwarding rules using "iptables" to allow specific applications to come through the firewall.

Badges for access control to internal devices, Internet access, and application access are implemented using "tc" and "iptables", and "squidguard". Badges are implemented in the same way regardless of whether they are implemented at the host or at the Room since the room is simply an IP range instead of a single IP.

6.4.3 Resource Management

For resource management, Eden uses the traffic shaping rules of "tc" for high speed priority. The traffic shaping rules are set by choosing which traffic to conrol, when the rule is in effect, and what level of traffic control is desired. For instance, users can apply a high speed priority rule for all types of traffic, during all times of day, to be applied to the highest class set up in "tc". Then, users can drag this rule to a host/room to give that host/room preferred network usage. All other hosts will become secondary to the needs of the host assigned this kind of rule.

For shaping, the traffic type is specified by port range or port keyword ("8080-8090" or "web"). The level is the class the traffic is to be assigned by "tc". "tc" will take care of shaping the traffic from there. If the traffic is set to the block level, a special "iptables" rule will be set up to block it.

6.4.4 Network Monitoring

To monitor the speed of the network and individual devices, Eden captures incoming and outgoing packets every 5 seconds and calculates the speed per second.

6.4.5 Help/Troubleshooting

For help, Eden inputs help information manually in advance, and the Smart Guide retrieves the information. For troubleshooting, Eden uses command line tools such as "netstat", "ping", and network monitoring information discussed in 6.4.3.

CHAPTER 7

EDEN EVALUATION

7.1 Evaluation Goal

The ultimate goal of the evaluation of Eden is to answer my second and third research questions stated in Section 1.4:

Q2. Does a new interaction model based on direct manipulation enrich users with no technical knowledge of networking and help them begin to understand the conceptual model and functions of the home network so that they can carry out basic management?

Q3. Does a new interaction model based on direct manipulation help users with informal knowledge of networking understand the conceptual model and functions of the home network and better perform tasks in terms of effectiveness and efficiency, compared to the network management tools they have used in the past?

I answer these questions through two separate evaluation sessions. One session examines the interface design choices of Eden. Because the success of direct manipulation depends on the design choices for its visual representation and task activation paradigms, the design choices of Eden will affect the quality of the user interface. In this evaluation session, I especially want to examine the metaphors of Eden. Eden adopted metaphors to convey the conceptual model of the home network and

operational models of management. The purpose of this first session is to see how effectively these metaphors succeed at their roles.

The other evaluation session is to demonstrate the usability of the user interface of Eden as compared with the usability of existing management tools. In this evaluation, I examine Eden's effectiveness and efficiency as well as user satisfaction for each tool. Then, I present my findings on which interface factors lead to any different results between the quality of Eden and existing tools.

After discussions of study participants in Section 7.2 and evaluation methodology in Section 7.3, detailed evaluation methods and results for each evaluation session are discussed in Sections 7.4 and 7.5.

7.2 Study Participants

For the study, I recruited 20 participants (hereafter, referred to as P1, P2, … P20) by word-of-mouth and emails to organizations. Figure 33 shows the distribution of the participants.

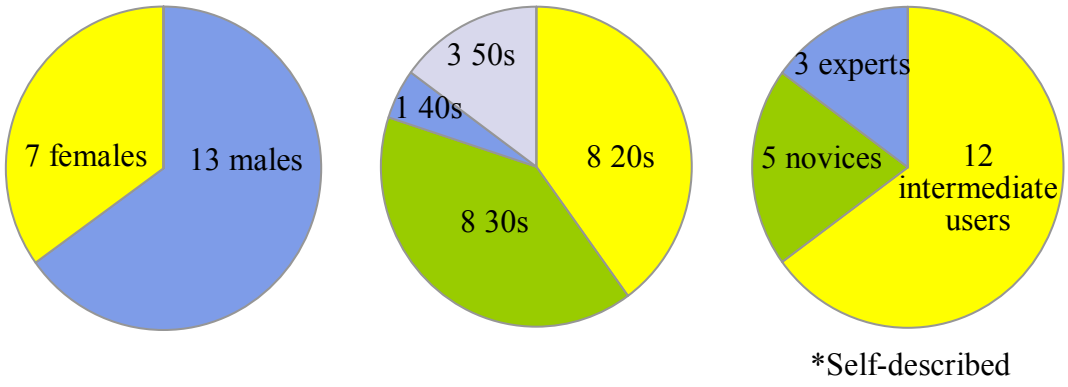


Figure 33: The study participants

With regard to the network experience and the level of technical knowledge of networking, the primary target users are novice and intermediate users as described in Section 3.4. However, I included 3 expert users to broaden the range of the study participants. Before the evaluation session, I asked the participants to describe their network management experience and to self-estimate their technical knowledge level. The criteria for determining their technical knowledge levels are same as those used in the formative study.

- Novice users are those who have no technical knowledge of networking and who simply use "ready to use" computers that someone else has set up.
- Intermediate users are those just enough networking knowledge to be able to connect the devices to their home network and use them. Intermediate users have to ask someone else for assistance to do any network management.
- Expert users have some kind of formal or technical training regarding networking. They can manage all their home networking on their own.

Although it looks as though there are clear borderlines between novice, intermediate, and expert users, their actual knowledge levels were continuous on a scale, ranging from no knowledge to expert-level knowledge. The level of technical knowledge of the intermediate users varied greatly from person to person. Some self-described intermediate users literally just knew how to connect computers to the home network using built-in tools OS. Some intermediate users did not know that all of the computers on the home network share the home network resources. Some intermediate users did not know how to make the home network secure. Their management experiences were very different from person to person as well.

Most participants obtained informal knowledge of networking to perform management tasks from online and acquaintances such as friends and family members. Only a small number of users used product manuals or asked company professionals.

All participants had a home network with 2 to 7 network devices including computing devices such as desktops, laptops, and PDAs and other networked devices such as network printers, game devices, and VoIP phones.

As in the formative study, the tools that the participants mostly relied on were the router interface and tools built into the OS. For membership management, that is, device connection and wireless network management, all users relied on the router setup interface and tools built into the OS. All intermediate and expert users had done membership management by themselves. For access control, 7 users used OS firewall software and commercial security software such as ZoneAlarm and McAfee. To check their network status, 10 users relied on the router interface and built-in OS tools. Some users used websites (e.g. speakeasy.net) to test individual computers' network speed. None of the test users had done resource management yet. For troubleshooting, 12 users used the tools built into the OS and the router. This data on network management tools gathered showed the same pattern as the one gathered from the formative study.

When the users needed help managing their home network, they tended to ask either company professionals or acquaintances including friends and family members. Some of them also relied on online information.

All participants except one intermediate user expressed a strong willingness to self-manage their home network if they were given easy-to-use network management tools. Some novice and intermediate users expressed a strong eagerness to self-manage their home networks, saying "Of course'" (P11, P17) to a question, "Are you willing to self-manage your home network if you are given easy-to-use management tools?"

7.3 Lab Experiment

I conducted a lab experiment in which I built a home network room equipped with Eden and 4 client devices. The experiment allowed me to evaluate how the participants used Eden in a controlled environment. To explore Eden's user interface, I was able to observe step by step how the participants understood and used the metaphors and what knowledge they got from them. To test usability, I measured how accurately or quickly the users performed given network management tasks with each tool.

One drawback to the lab experiment was that it did not allow evaluation in real home network settings. The context of the home network in my lab were different from those that real world users face in that the number and types of devices differed from what users have in their homes. In addition, the details of network troubles are different from what users experience with their home networks. Furthermore, my lab experiment did not allow a longitudinal evaluation in real home network settings. Therefore, it could not provide answers to questions such as "Does Eden encourage novice and intermediate to participate in their network management?" Nonetheless, I chose a lab experiment because the primary purpose of this evaluation was to examine the user interface of Eden in selected tasks rather than to examine how well Eden can support various individual home network settings. The variety of home networks meant that an in-situation evaluation would have made it difficult to control for environmental differences due to the different device types, topologies, and uses of each home network.

7.4 User Interface Metaphor Evaluation

This section first discusses the general metaphor evaluation criteria and the evaluation criteria of each metaphor of Eden. It then discusses the evaluation procedure and then the evaluation results.

7.4.1 Evaluation Metrics

The primary value of the user interface metaphor is that it can facilitate user understanding of the conceptual model of an abstract, unfamiliar content domain by using familiar concepts. Consequently, the user interface metaphor helps users anticipate how interface actions might affect the system. In the evaluation, I wanted to examine how well Eden's metaphors carry out their role of metaphor in the home network management domain.

At the same time, I wanted to examine what mismatches the Eden metaphors cause and whether Eden overburdens users with metaphors that are too literal, unnecessary, or functionally irrelevant.

These evaluation goals led to the following metaphor evaluation questions, which served as the evaluation criteria for the Eden metaphors.

Q1 Does the metaphor help users construct more accurate conceptual models of the home network?

Q2 Does the metaphor provide a good correspondence between actions and their intended effects?

Q3 What aspects of the metaphor mislead users?

Q4 Does the metaphor overburden users with details that are too literal or functionally unnecessary?

7.4.2 Evaluation Methodology

This section describes how I answered the metaphor evaluation questions for the Eden metaphors described in Section 7.4.1

To examine how well Eden's metaphors carry out their roles as intended, I first categorized the Eden metaphors into two types according to their roles as shown in Figure 34. The two types are not exclusive.

Type 1 metaphors – House, Link-Pipe

Type 2 metaphors – House, Link-Pipe, Badge, Assistant

Figure 34: Metaphor types based on their roles

Type 1 metaphors are designed to convey the basic architectural and operational model of the home network as a distributed system. The Home and Link-Pipe metaphors are Type 1 metaphors which provide the residential user with a foundational understanding of the home network. Type 2 metaphors are those designed to facilitate management tasks. All four metaphors - House, Link-Pipe, Badge, and Assistant – are Type 2 metaphors. The Home metaphor supports membership management. The Link-Pipe metaphor supports network monitoring. The Badge metaphor supports access control and resource management. The Assistant metaphor supports help and troubleshooting.

I then made evaluation criteria for each metaphor based on its role and its potential for mismatches. The details of the evaluation criteria for each metaphor are described later with the evaluation results.

The metaphor evaluation consisted of three sessions – Test session 1, Metaphor evaluation session, and Test session 2 (Figure 35).

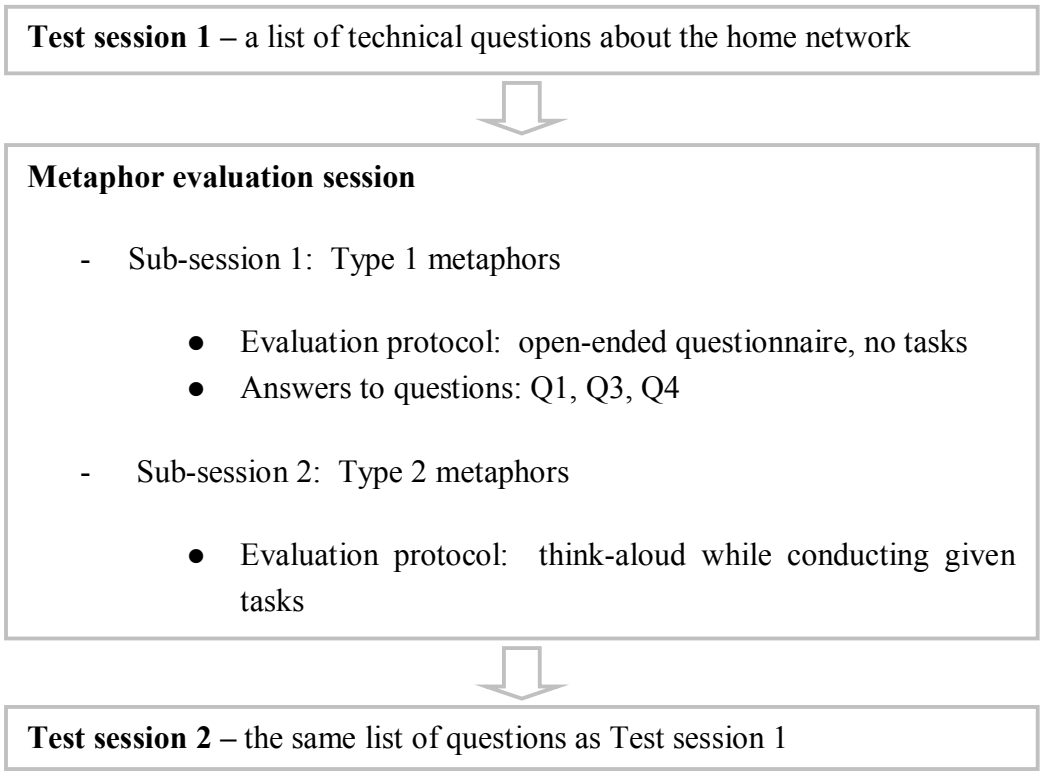


Figure 35: Metaphor evaluation procedure

In Test session 1, I asked users to answer a list of questions about their technical knowledge of the home network. This session helped me learn the users' technical knowledge levels and thus be better able to categorize the users according to their knowledge levels as I perceived them together with their self-reported knowledge levels. The list of questions is appended to this document.

In the metaphor evaluation session, users first had an about 5 minute brief instruction session about what Eden is for before they participated in the evaluation. They were, however, told nothing about the Eden metaphors.

The metaphor evaluation session consisted of two sub-sessions. The first sub-session was to examine Type 1 metaphors. In that session, I wanted to examine how well

Type 1 metaphors convey the conceptual model of the home network. The evaluation protocol was a questionnaire. I asked the users conceptual questions based on each metaphor's evaluation criteria. The questions were mostly open-ended questions such as "Can you guess what the Home means?" and "Can you tell the difference between objects inside the Home and those outside the House". The full list of the questions is appended to this document. In this session, users were not asked to perform any tasks, but they were free to explore Eden's user interfaces. Through this sub-session, I intended to find out answers to metaphor evaluation questions, Q1, Q3, and Q4 for Type 1 metaphors. Q2 is excluded because it is related to performing tasks.

The second sub-session examined Type 2 metaphors. In this sub-session, I asked users to perform a set of specified tasks and observed how they perform these tasks using Eden. I used a think-aloud protocol but, if necessary, asked users questions while they were performing selected tasks. With each metaphor, I wanted to investigate the following questions – "What actions do users take to perform the selected tasks?", "Why do they decide to take these actions?", "What results do they expect from these actions?", "What happens as a result of their actions", and "How do the users interpret the results of their actions?" Answers to these questions were intended to help me get answers to metaphor evaluation questions Q1, Q2, Q3, and Q4 for Type 2 metaphors.

In Test session 2, I asked users to answer the same list of questions that they responded to in Test session 1. Then I compared their answer sheets from Test session 2 to the ones from Test session 2. This provided objective data on the Eden metaphors' effects on the users' conceptual model of the home network.

7.4.3 User Interface Metaphor Evaluation

This section discusses the evaluation results of the user interface metaphors. I discuss the results for each metaphor.

7.4.3.1 Home Metaphor

As a Type 1 metaphor, the Home is a spatial metaphor to represent the home network in the form of a physical space on the screen. As a Type 2 metaphor, the Home metaphor supports membership management of client devices.

In this section, I first discuss the evaluation criteria and results of the Home metaphor as a Type 1 metaphor and then discuss the ones as a Type 2 metaphor.

As a Type 1 metaphor, I investigated the following evaluation criteria:

- "How do users recognize the location of a device on Eden?"
- "Do users recognize the physical boundary of the Home as the logical boundary of the home network?"
- "How do users place mobile devices?"
- "How do users recognize fixed networking objects vs movable client devices?"

With regard to, "How do users recognize the location of a device on Eden?", all 20 participants immediately relate the device location on the Home to the physical location of the device in the real house. In addition, several users associated the location of the device in the Home to the ownership for that device and computer usage patterns of the household. For instance, P2 said that when a device is placed in a bedroom, it is a private device, not a shared one, but when the same device is placed in the living room of the House, it should be accessible by anyone in the House. P18 said that the computer in the living room is a kind of computer for everyone, but that the computer in the child's room is the child's (or children's) computer. P6 said that a desktop computer is in the living room because the family spends most of their time in the living room.

Some users related the location of a device to access right properties associated with a speicfic location in the House. For instance, P3 associated the location change of a device in the Home in the following way.

> *"There are two cases. The first one is the physical move. The second one is access capability. Each room has its own restriction policy. The living room has its own access policy. The child's room has its own access policy. When the iphone is in the child's room, it cannot access something. But when it is in the living room, it can access that." (P3)*

With regard to, "How do users recognize the physical boundary of the Home as the logical boundary of the home network?", most users correctly recognized the meaning of the spatial physical boundary of the Home as the logical boundary of the home network. They inferred based on the physical boundary of the Home that the devices inside the Home were the part of the home network and that devices outside the Home were not. For instance, about the devices inside the House,

> *"Based on this (House), they are a part of the home network. Partly because of previous knowledge and because their layout chose them as being there at their house." (P12)*

> *"Yes. because essentially the visual motive that you choose that even though these are different colors, theyre within what is interpreted be the roof top of the house, they are under the roof top of the Hous, so they are visually associated with all these physically within the House." (P18)*

On the other hand, for some users, the fact that a device is inside the Home was not sufficient to tell the membership of a device. They emphasized the need for the topology link for a clear indication of the membership of a device.

"I don't know. That doesn't say wireless, so technically I don't know if those are even Internet accessible, and to me there's no wire connection or anything. That (a topology link) gives me the sense that these things are connected to the home network." (P8)

"Yes. They are a part of the home network. The computer is a part of the home network if it is connected to the router (by a link). Otherwise, it is not. Any line would be helpful." (P15)

About the objects outside the Home such as computers in Newly Detected Device Area and the Internet, users recognized them as not being a part of the home network. This is, presumably, due to both their previous knowledge and the graphical representation of Eden.

"They are not part of the home network – because they are outside the house. The home network is classified as any devices you can see in the network, but the ISP doesn't have a device actually on the home network." (P5)

"I would say it's not because it's not contained in the house. I wouldn't think it's a part of the network, and plus there is no connection to it right now." (P8)

On the other hand, P2 and P3 were confused about computers outside the House. They said that it could be a wirelessly connected device sitting outside the Home such as the yard or the deck of the house. P16, who has knoweldge about the networking architecture of the infrastructure-mode home network, was also confused.

"I don't know. It says it's a newly detected device. I don't know if it is or not because I'm assuming that the network might (have to) see it for Eden to see it. So, I guess in that sense, it is." (P16)

With regard to "How do users place mobile devices?," all but one user preferred ownership-based placement for mobile devices over habitat-based placement or any other ways. In fact, for most of the study participants, ownership-based placement corresponded to habitat-based placement because they thought of the room of the person who owns the device as the place where that user would use the device most. For instance,

"For laptop machines, it might get moved around. I would set them according to the owner." (P16)

"Because the computer is essentially owned by that individual. That's the best way to associate it with the individual. It's a mobile device, but it's used by only one person." (P18)

P4 expressed his own categories for mobile devices by using the terms "mobile devices" or "general miscellaneous."

"Well, mobile devices move a lot. If I choose one place, its ownership will be more preferable, but if I could make my own category, that would be better - maybe simply mobile devices, general miscellaneous…" (P4)

In Eden, only client devices are movable. Infrastructural core networking objects such as the router, the cable modem, the ISP, or Internet are not movable because their affiliation is not changeable. With regard to, "How do users recognize fixed networking objects vs. movable client devices?", all participants who had knoweldge of networking

well recognized the difference between them. This also helped the participants who did not have technical knowledge of networking grasp the conceptual model of the home network as the infrastructure technology.

For the Home as a Type 2 metaphor, users were asked to perform membership management tasks in the following scenarios - 1) You bring a new laptop to your home and want to connect it to the home network; 2) You want to remove your friend's computer from your home network after your friend left. I then observed what actions users took and why and whether or not the Home metaphor had any breakdowns

Most users immediately moved the device inside or outside the Home based on their understanding of the Home metaphor. They liked being able to move a device inside the Home or outside the Home to control its membership. On the other hand, P6, P7, and P8 preferred leaving the device inside the Home to remove it from the home network, instead of dragging it outside the House.

> *"It doesn't make sense to me to have the computer ouside the Home if I don't keep my computer ouside the house. It would almost be better for me if it were a darker color if it's connected to the family, like your computer buttons could be a lighter color or faded color. But that's connected but still inside the room." (P7)*

> *"I think it makes sense just to disconnect it; you may use it again. So I just want to disconnect it (leaving it inside the house) rather than dragging it out. I want to add a guest computer to the guest room." (P9)*

The topology line was important for the feedback about the membership change of a device. Ten users strongly preferred having the topology line. P1, P4, and P8 even tried to draw a link between the router and the device after they dragged the device inside the Home even though the topology link option was not enabled.

"The line makes it clear that the computer is now a part of the home network. If the topology line is not there, I'll be confused. I think the line is very useful." (P11)

"Without the link, I guess I am not sure if this computer is connected to the home network. I guess I drag it outside the House. Again, it's just intuitive." (P13)

There was a user who wanted to distinguish visitors' devices from his own devices so that when devices are added to the home network he could control visitor access to data and devices shared in the home network.

"I would like a question that comes up and immediately asks me 'Is this a guest computer or is it a home computer?' So if I see a guest computer, immediately I would like all my file access to be automatically blocked unless I say. If I've added something, a very quick pop-up says "guest or trusted computer". (P6)

The Home metaphor worked very well for the study participants regardless of their technical knoweldge level. The users easily grasped and liked the spatial concept of the House. Users thought the physical layout of the Home useful. To novice users, this physical layout of the Home was very helpful mainly in that they thought that the physical layout of the Home matched what they thought about the home network. For instance, P7, P15, and P20, all novice users, respectively made the following comments:

"Yeah that's very helpful. Because I think in very physical terms. If I could do that, that would be more fun to me. The fact that it's in the room is very helpful." (P7)

"It's good to have the physical layout of the Home in the sense that it is easy to imagine the home network if it is represented in the physical layout of the House. People would be able to think of the home network in the real context of their home. The physical layout of the home network makes it easy to understand." (P15)

"It is exactly (the) same as what I have in my mind." (P20)

To intermediate and expert users, the physical layout of the Home was also helpful although several users pointed out the breakdown of the Home metaphor about regarding mobile devices.

"It might be useful to know where the computer physically is located and be able to organize it, especially if I have a more complex network at some point." (P5)

"The space can give you the notion of where your (computers) are. If you give the sense of space, it will be better. Because if I don't see that space, I will be confused if this is my network or this is my computer. Even if that computer is connected to my router, if you don't give me the space, I don't know where this computer comes from. Even the router, if it is not in the space, I don't know where the router comes from. If this computer is in the living room, then I know my friend is in the living room and trying to use my router, I'll give you the permission to access my home network." (P11)

"Yes. It's intuitive. You are setting up the home network. Then you are using the home style motif. That makes sense." (P18)

"It makes sense. It is helpful. The ability to move around computers would be nice for some people. The only place that I think would come up and be confusing is when you move a computer from room to room. I'm guessing Eden does not have a way to detect the computer was moved. So that might confuse someone." (P16)

7.4.3.2 Link-Pipe Metaphor

The Link-Pipe metaphor is a metaphor to represent the network topology and traffic flow. As a Type 1 metaphor, it tells how the home network works as a distributed system - the router and the modem as the gateway from the home network to the Internet or vice versa; all client devices at the leaf, sharing the same network bandwidth resource. As a Type 2 metaphor, the Link-Pipe supports network monitoring and troubleshooting.

I discuss the evaluation criteria and then discuss the evaluation results of the Link-Pipe metaphor as a Type 1 metaphor and as a Type 2 metaphor in order.

I evaluated the Link-Pipe as a Type 1 metaphor according to the following evaluation criteria:

- "How well does the Link-Pipe convey the conceptual and operational model of the home network to users?"

As a Type 1 metaphor, the Link-Pipe metaphor was very helpful to the study participants, especially to intermediate and novice users. The simple graphical visualization of the Link-Pipe metaphor greatly helped the participants grasp how the home network works. Before trying Eden, 10 users did not know how network traffic flows between a computer in the home network and outside the Internet or vice versa. To the prompt, "Tell the network traffic path when you use a Web browser to access the web

site on the Internet", in Test Session 1, all novice users, P7, P14, P15, P17, and P20 and 5 intermediate users, P1, P9, P10, P11, and P12, gave an inappropriate response. For instance, P1 and P7 responded with "Laptop's web browser – Internet (e.g. www.youtube.com) – Router – Modem – ISP". P12, P15, P11, P17, and P20 responded with "Laptop – Modem – Router – ISP –Internet". However, by using Eden during the study, these users learned how the network traffic flows and answered questions correctly later in Test Session 2.

All novice users and several intermediate users learned the concept of shared bandwidth among devices of the home network via the Pipe. For instance, P1 and P9, both of whom are intermdiate users, had not realized that the total network bandwidth and speed of the home network are shared among multiple devices in the home network.

> *"I did not realize that the network speed is shared among computers in the home. If more computers use the home network, the slower the network speed of each computer could be. The network speed is not evenly divided to each computer? Ahhh... then I cannot turn on multiple computers at one time/ Ahhh... that's why I experienced network disconnections so often when I did not get my wireless home network secure." (P1)*

> *"Before, I didn't know that computers share the network speed of the router. That means the sum of individual computers is equal to the router's total speed? Ah... I didn't know that. If I'm working or something at home, I mean, if it is work-related, and my son is taking that much space (bandwidth) there, then I need to tell him that he is taking too much space (bandwith) and not allowing me to work as best as I would like to because of the amount of network speed that he is using. Before, I didn't know that it was. I didn't realize that the router carries the total amount of the speed,*

and the total amount of the speed breaks down depending on the number of computers that are using it." (P9)

P5, P9, P10, P11, P13, and P17 learned the conceptual model of the router as a gateway to all other client devices on the network hierarchy, bridging the Internet and client devices via the network topology represented by the Link-Pipe. This conceptual model of the router and client devices represented in graphical separation helped the participants recognize the conceptual models of different control levels. P5, P9, P13, P14, and P17 did not know the difference between taking actions at the router level and taking the same actions at an individual device level.

"If that application icon was on the router, then skype is blocked by the router versus, maybe, if that icon is on the computer, the computer has that application blocked - because visually, there is a separation between the computer and the router. So, if you put it an icon next to one, it does not belong together. It's taken apart. So visually, I can see that if there is an icon "skype is blocked on the computer" or "skype is blocked on the router," it's just visually easy to see because they are separate ones on the display." (P5)

"If you block it (certain application traffic) at the router, if that's possible, I don't know. If it is, because it seems that the whole idea is that the router perceives the signal from outside, but if you block it at the router, then I believe no devices could use the Internet. Based on the idea, as a gate, the gate is open or closed. The idea is almost like a mechanical object, not as a digital object. So if the gate is open, you can go through it. If the gate is closed, you can't. And there's just no middle ground. That's the way I view it. So for me, it would actually be helpful to show the router maybe as

a hallway to many doors. So there is only one way going this way, but there are four or five doors going this way." (P7)

Overall, the graphical network map of the topology and traffic flow helped users determine the network speed of the home network and individual computers. For instance, two novice users, P7 and P15, respectivly, stated,

"Any graphical representation is very helpful to me because I need tangible things." (P7)

"Visual information is very helpful. Even this simple animation gives me a sense that my network is working properly." (P15)

In addition, the visual traffic map of the whole network helped the participants find out the network bottleneck points as well as check the speed of the network and individual client devices. A considerable number of intermediate users and novice users did not know how to check the speed. Here are some examples.

"The speed map is necessary. For instance, when watching youtube or online videos, sometimes I feel it's too slow. Then, I want to check the overall speed map of the network and see if other computers consume network resources, and if so, kill them." (P2)

"It's very good information visually. Before, I didn't know how to check the network speed of computers. I just thought my computer is slow, but I didn't know what to do." (P11)

"Before, I never checked the network speed. If I encountered slow network speed, I would try to reboot the computer, the router, and the modem." (P13)

"It tells me at a glance. For instance, if I'm using a computer and can't access the Internet, I check that and see if there were no boxes between that computer and the router. Then I would know that's where the problem is rather than wondering if the problem is between the router and the modem or the modem and the external." (P16)

With regard to visualizing applications that are currently active on each device, there were varying opinions regarding between awareness and privacy issues. Some users liked to know what applications are running on the network, while other users worried about other people's seeing their information.

"Those will show which applications are currently being connected to the Internet. But then I would be concerned about privacy issues. Well, if I'm using a certain application and don't want someone else to see it, (Llet's say I don't want my sister to know that I'm using yahoo messenger.), then I want to hide that. Well, if you are a parent and all of your children are young, then you would want to see what kind of programs are being used by them.. so.. for parental control." (P4)

"I think I would put it (network speed and application icons) in two layers - one for just status, where you have the links and then maybe another layer that gives move details. I would not like to show this (applications) to my mother. From the network perspective, it helps me to see applications. I also prefer to show wireless versus wired. (green

rectangles) That's network speed. Applications are applications that are running on the computer." (P6)

The unidirectional Pipe (network traffic is bi-directional) was not important to the study participants as long as upload and download speeds are separately specified. Several users wanted to see the speed and the network capacity at the same time, though.

Viewing the Pipe as a Type 2 metaphor, users were given two scenarios – 1) You want to check the bandwidth usage and network speed for the whole home network and for a specific device, 2) You suddenly experience slow web downloading speed with your laptop. You want to know where bottleneck points are.

Users quickly grasped the differences between the speed of individual computers and the whole network. The Pipe helped a lot the participants find the bottleneck points of the network.

7.4.3.3 Badge Metaphor

The Badge metaphor is a metaphor for applying network settings to devices. In Eden, it supports access control and resource management as a Type 2 metaphor. In this section, I discuss the evaluation criteria and results of the Badge metaphor.

For the badge metaphor, I investigated the following questions:

- "How well do the users understand the badge metaphor?"
- "How well do the users recognize the difference in access control between individual device-based, room-based, and network-based controls?
- "Does the badge metaphor have breakdowns?"

To investigate how well the particpants would recognize the basic concept of the badge metaphor, I asked the them to respond to the following: – 1) You want to block

your friend's laptop from access to your computers in order to prevent your friend from accessing private files in your computers, 2) You want to block this computer from access to a certain website, 3) You want to block this computer from access to the Internet, 4) You want to block P2P and IM applications.

To investigate how well the participants would recognize the difference in access control between individual device-based, the room-based, and network-based devices, I asked the particpants to respond to th following tasks – 1) You want to block all guest devices from accessing other devices in the local network for privacy. I also asked users these conceptual questions: 1) If I put badges in the room, what effects do you think it has on the devices in that room?, 2) What's the difference between putting badges on an individual device, on a room, or on a router.

With regard to "How well do the users understand the badge metaphor?", most users used the badge appropriately during the first trial. However, several users (P2, P4, P5, P16) did not understand the badge metaphor during the first trial, but quickly got the concept of the badge metaphor after several trials and errors. For instance, P2 first tried to find the IP address of the target device for web site blocking. P2 right-clicked the target device to see if she could find blocking website forms. P2 finally selected a "Sites" badge and put it on the device. P2 said the badge was much more convenient than existing ways because using the badge - took just two steps – dragging and dropping the badge, and then entering the URLs, without having to deal with an IP address or any other mapping. P4 also first tried to right-click badges and then drag them to the device. More examples were the following:

> *"Actually, I clicked on the icon (badge), and it didn't do anything. So actually I expected some menu would pop out, but that didn't work. So the second option is just drag because you have other things dragable." (P5)*

"Well, first I tried to just select the laptop and then click "Sites" from the menu, but it didn't seem to select the laptop when I clicked on it. And so, then I clicked just "block websites" and nothing happens. So the third thing I tried was drag it. I knew what happened when I drag the computer to the computer inside the House, so I tried to drag the 'block websites' icon." (P16)

Although these users tried other ways before they finally discovered the intended way to activate the badge, they quickly understood the badge metaphor and liked the badge concept in terms of usability.

With regard to "How well do the users recognize the difference in access control between individual device-based, the room-based, and nework-based controls?', all users easily recognized the differences based on the graphical representation of the device map. For example, P6 said:

"It looks quite obvious because they (the router and the computers) are physically separated. If you block here at the router, it's very easy to see all of these guys (computers) are going to get blocked." (P6)

They also liked the different levels of access control – they could block the whole network, they could block individual computers, or they could block a certain group of devices. Users P9 and P11, had only recently learned the conceptual difference of different access control levels through Eden, and P11 stated the following:

"Before, I didn't know I can block an individual computer. Now if I put a badge here on a computer, OK, now I don't need to block the whole router (i.e. network) and I can block an individual computer or I can block a living room (per group). So this graphical map of the device gives me a sense of which control levels I can take." (P11)

Room-based access control was also well understood by the users. Many users saw room-based access control as very useful in real situations for grouping a set of devices that would all be given same access control rights. For instance, P6, an expert user who has two children and wants to do safer Internet for children, and P11, an intermediate user who has friends frequently visiting his home, mentioned the following.

> *"It helps. For instance, for a child's room, let's suppose that there are three laptops. Then you don't have to do one at a time and one at a time. So I think it's very good idea. Sometimes, my friend's child and my child's friends come in. So I'm gonna put this guy right here (in the child room) so that automatically all those range of access controls that I've done are applied so I don't have to reconfigure for these kids." (P6)*

> *"Room-based access control makes sense. I don't want my sister or any friends to access my computer. In that case, the room-based access control will be useful." (P11)*

However, room-based access control requires more graphical affordance, as P5 and P12 mentioned.

> *"There wasn't a lot of feedback. I don't know if the room has the special property if there is some indication like it would work. But there is no indication." (P5)*

> *"It makes sense as something that tells you you can block a room, like as a whole, since right now there is no cue that tells you can do it." (P12)*

With regard to "Does the badge metaphor have breakdowns?", users (P8, P15, P17) all put badges on the link between the router and the target device instead of (directly on) the target device. P8 mentioned one reason.

> *"I would think maybe for each point in the connection, if you put something in the pathway, then it will not let anything get there or (let) anything come out." (P8)*

For resource management, I asked users to respond to this prompt - You will use Instant Messenger (MSN) video conference with your laptop. You do not want to be interrupted by other computers using the Internet while you are doing video conference. Therefore, you want to give high network priority to your laptop.

Most users immediately dragged badges onto the devices since all of the particpants had used the badges for access control. However, there were several users who put a badge on the link between the router and a computer instead of directly on the device itself.

Overall, regardless of their technical networking knowledge, the users absolutely liked the badge concept for network settings in terms of usability. They especially liked its affordance and immediate visual feedback. Here are several users' comments on the usabilty of the badge metaphor.

> *"Yes. Well. So I've never tried to block devices on my router, but I have a vague notion of what the interface looks like, and I have to find the right interface and then figure out how to block. I don't know if I have to enter a MAC address code or some other DHCP thing. So I'm not sure how I do it on my wifi router interface. This makes more sense to me, to use drag and drop onto devices and stuffs happen." (P5)*

"Yes. I think it's much better. It's much easier to use graphical icons. I've used Linksys. I've used balkin. I've CompUSA. I've used dlink. I have used all four, and I think this is the best. My only concern is that if I have three or four icons, it would be creepy" (P6)

"Initially, this is easy. I don't see any real technical terms, so for someone that doesn't know, probably the most technical term I see would be 'server'. So other than that, it's really good because you don't get intimidated and even I know I actually use Linksys on this and (even though) I probably know about 75% of all the terms on here, I still get overwhelmed. You have to almost know like the definitions of them. This, you don't. Everyone knows 'Internet,' 'websites', 'device.' I think that's a big advantage. It's visual. It's almost like with one quick motion, you can do what you want to do. You don't have to click through the menu system and find it, start typing, and save the settings. This seems like all you do is click and drag and drop, and it's finalized." (P8)

"It is easier to see. It's like looking around and finding the setting." (P10)

"I think it's useful because it's a lot harder to go into this and tell it what to block and what not to block, because you don't have to go to the computer and find the IP address or Mac address or something. I don't many people that know how to do that." (P12)

"It's much easier than going to the router and trying to reserve bandwidth. I've never done QoS with the router." (P13)

"It's very simple to drag and drop." (P14)

7.4.3.4 Assistant Metaphor

The Assistant metaphor helps users use Eden and troubleshooting the network as a Type 2 metaphor. Smart Guide is intended to help users use Eden. HomeNet Doctor is designed to help users troubleshoot the network when they encounter a network connectivity or speed problem.

To investigate the particpants reaction to the Assistant metaphor, I asked the participants to respond to the following prompts: – 1) You want to know what the "block device" badge (or other examples) does and how to use it, 2) You suddenly experience a network disconnection problem with your laptop. You want to figure out why it happened, 3) You suddenly experience slow website download speed. You want to figure out why it is happening.

Through the evaluation, I investigated the following questions:

- "How do users use Smart Guide and HomeNet Doctor?"
- "Does Smart Guide and HomeNet Doctor increase the usabilty?"
- "Do they experience breakdowns?"

Most users clearly understood the drag-and-drop activation of Smart Guide and HomeNet Doctor. The names, "Smart Guide" and "HomeNet Doctor," explicitly told users their roles. Despite this, several users still tried to right-click target networking devices instead of using Smart Guide or HomeNet Doctor.

However, the preferences the participants displayed for Smart Guide and HomeNet Doctor were different regarding utility and usability. Only half of the partipants showed a preference for Smart Guide, whereas all of the participants were positive toward HomeNet Doctor.

The reasons that the participants liked Smart Guide included that its graphical user interface was intutive and easy-to-learn, resulting in comments like the following:

"I just kind of go quite easily across the whole diagram if I want and see all the information about it rather than having to like search or click on Linksys stuff like that. It seems easier to get to the information that I want. It's like automatic search." (P5)

"You don't have to go through and do. I know a lot of people that don't like menus. So you kind of drag around and find what you want." (P12)

"It's graphical, intuitive, easy-to-learn." (P13)

Around half of the users, on the other hand, did not like the way Smart Guide was activated. P4 and P6 thought it annoying to drag Smart Guide everywhere. Instead, they preferred to just right click on the target or smaller icon right next to the target.

Some users were skeptical about Smart Guide from the perspective of utility.

"This is very difficult to design because different users have different requirements. For example, I would like to see speed, I would like to see bandwidth, I would like to see dhcp server information. My mom does not care about DHCP server information. She would put this guy on this (a device icon) to see what this guy is doing and why my internet is slow. So it should be tunable. If you are a pure novice or if you are an expert. I like everything else, but this one is a little...." (P6)

"It didn't give very much information. The help function is pretty limited. Also, I guess another potential disadvantage is this is kind of generic help, where a specific router could have specific issues that it needs to address

and you can probably only find a document for that specific router. Those are disadvantages. For more general things, though, this seems very easy." (P16)

One interesting suggestion for Smart Guide was to incorparate online help information into Smart Guide.

"If it has just a user manual from the company, that's not quite as useful because usually the user manual from the company assumes things don't go wrong. But when things go wrong, they are always going to go to the Internet and search. So it might be useful, you know, if I went here and it's on the access rights to websites, and maybe it would show me searches on my favorite access about what access rights might be a problem or stuff. Or it would allow me to associate bookmarks with it. So in the past, I found articles that had been helpful and then I bookmarked them. Then I could throw them into this interface. Then it would show me those bookmarks that I've used in the past to troubleshoot." (P5)

Unlike Smart Guide, HomeNet Doctor was liked by every participant. The primary reason was its usability, compared to command-line troubleshooting methods or anything else. The following comments help to explain the users' thinking.

"Smart Guide is a bit strange to me. It's usually double-click or right click for advanced information. So I prefer right clicking for help. But Doctor is different. I really want to see where the doctor is now and fixing which problem. So I like the doctor because you can put it on different places and thus fix different problems, so it gives me a sense of where the problem is, but when I just need advanced information for something, I just like to right click." (P11)

"I think it's good because you can do it all from here. You don't have to go troubleshoot each computer individually and also because like earlier, you will be able to know where it is. Like no connection, if the problem was between the computer and the router, then I wouldn't go restart the modem. Disadvantages? I think if you had more technical knowledge, you could find out more by going to the computer and digging around all the menus, but for most people, I think (this) is really helpful because it localizes the problem." (P12)

"Eden seems much faster and more convenient in that I just have to drag over and click a couple of buttons or. as you know from before, you have to go through 'network card configuration' and turn it off and back on, in that way, or else restart the whole computer." (P16)

There were some interesting suggestions for HomeNet Doctor. P5 suggested integrating online troubleshooting articles and resources.

"It is really nice that you can just drag and drop onto particular items, and then it will help you out and provide some suggestions. What would also be nice is if it would allow me to work on my own data sources as well. And so, either I have bookmarks or searched google groups or seen archives to figure out what common things maybe other people are doing. So you could also make this into a collaborative interface where you say 'People who try to debug their desktop using Eden find these articles helpful.' type of thing." (P5)

7.5 Usability Evaluation

This chapter discusses the Eden usability evaluation. It first discusses management tools that I will compare Eden with. It then discusses the usability evaluation criteria and a list of selected tasks that users were asked to perform with tools including Eden. Lastly, it discusses the evaluation procedure and findings.

7.5.1 Management Tools for Comparative Study

This evaluation explores the usability of Eden. In the evaluation, I demonstrate the effectiveness and efficiency of Eden through a comparative experiment with existing network management tools - Cisco's Network Magic and tools built into a router (the Linksys Wireless-G Broadband Router with SpeedBooster web interface) and tools built into an operating system (network connection wizards and command-line tools such as "ping" and 'netstat').

According to the formative study, the tools built into the router and OS (e.g. Local Area Connection and Wireless Network Connection, netstat, ping, etc) were the tools that users rely on most to manage their home network. Therefore, I decided to compare Eden to these tools. I sampled the Linksys router interface for this evaluation. For OS tools, I chose by default the Windows OS tools. In addition to the router interface and OS tools, I compared Eden with Cisco's Network Magic, which is the only network management tool designed for the household at this point. There are many software tools that support some tasks of home network management, for instance, ZoneAlarm for firewall and access control. However, other than Network Magic, there is no network management tool designed for the context of the home network.

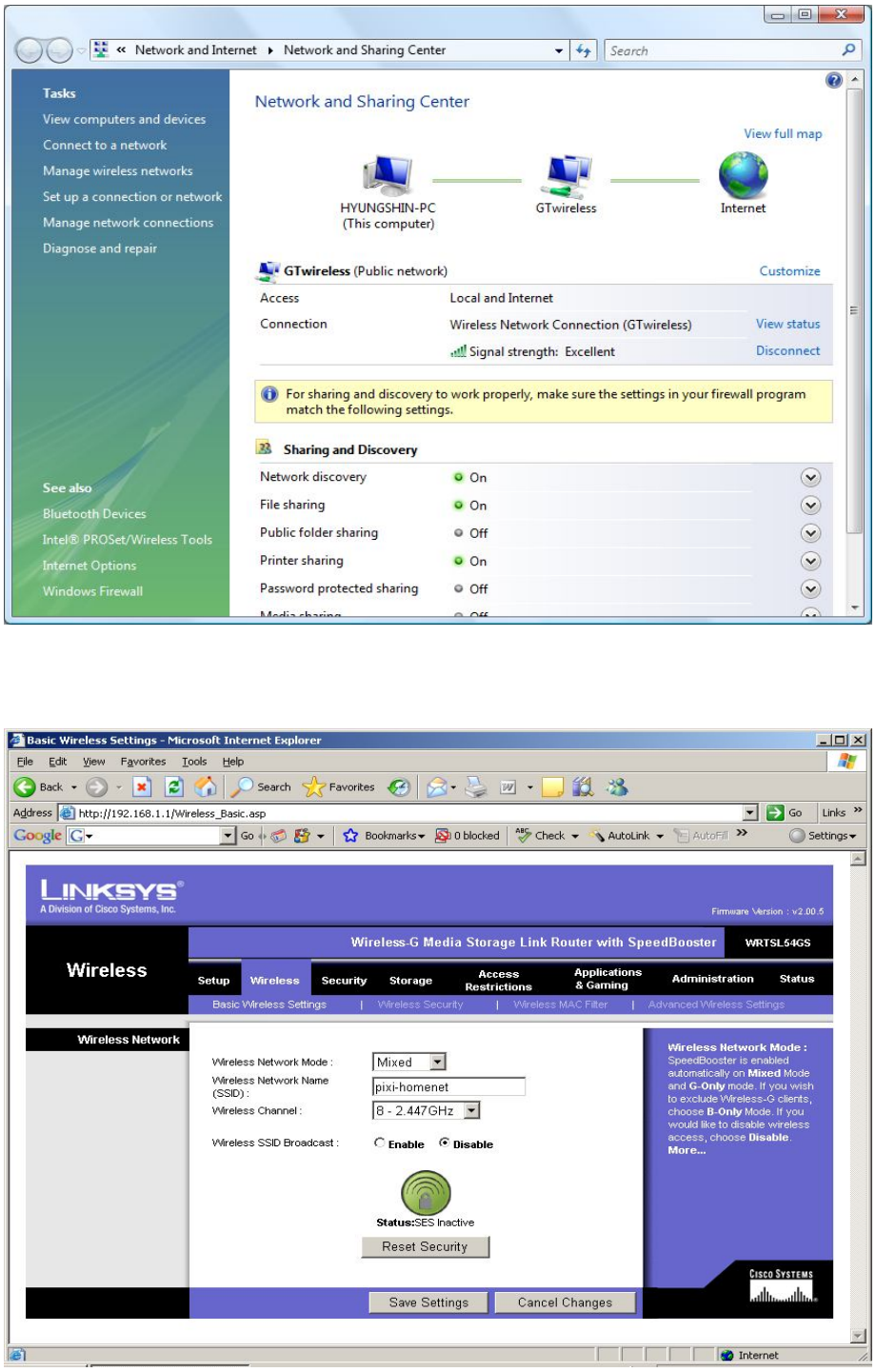


Figure 36: Tools built-into Windows OS (top) and the Linksys Wireless-G Broadband Router (bottom)

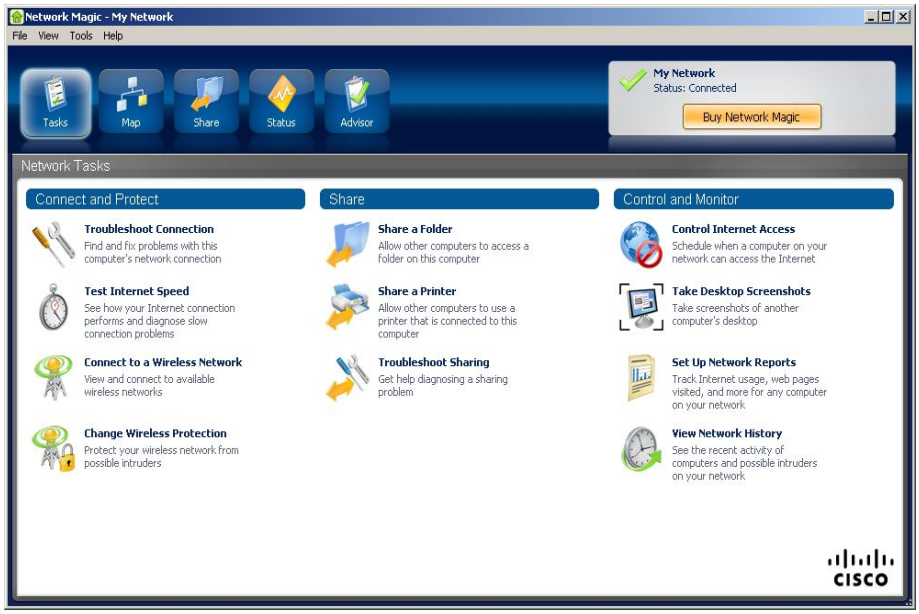


Figure 37: Cisco's Network Magic

7.5.2 Evaluation Metrics

For usability testing, I measured the following criteria for each tool. I collected not only quantitative data but also qualitative data.

Table 1: Usability evaluation criteria

Effectiveness	Quantitative data: task completion rate vs. failure rate Qualitative data: factors that make a difference in effectiveness between Eden and other tools
Efficiency	Quantitative data: task completion time Qualitative data: factors that make a difference in efficiency between Eden and other tools
User satisfaction	Quantitative data: overall tool preference order Qualitative data: overall pros and cons of each tool

7.5.3 Evaluation Methodology

To compare the three tools, I first made a list of tasks of the tools (Table 2) and categorized them according to the five management categories discussed in Section 3.1. I asked users to perform one or two tasks per category and measured the evaluation criteria of Table 1. Any tasks not belonging to the five management categoires were excluded from the evaluation.

Table 2: Management tasks of three tools

Management category	Management tasks	Eden	Network Magic	Router/ OS
Membership management	T1: Add a client device	✓	✓	✓
	T2: Remove a client device	✓	-	✓
	T3: DHCP server, client address range, DNS/DDNS setting	-	-	✓
Access control	T4: Block Internet access for client devices	✓	✓	✓
	T5: Block applications	✓	-	✓
	T6: Block websites	✓	-	✓
	T7: Designate a server device (web/file server)	✓	-	✓
	T8: Block internal devices	✓	-	-
	T9: Block anonymous Internet requests, filter Internet NAT direction/multicast	-	-	✓
Network monitoring	T10: Check the connectivity status of a device	✓	✓	✓
	T11: Check the network speed of a client device	✓	✓	✓
	T12: Check the network speed of the network	✓	-	-
	T13: Determine network bottleneck points	✓	✓	✓
	T14: Show the histories of Internet usage, visited websites, applications	-	✓	-
Resource management	T15: Assign high speed priority for a device	✓	-	✓
	T16: Assign high speed priority for an application	-	-	✓
	T17: Assign high speed priority for an Ethernet port	-	-	✓
Help/ Troubleshooting	T18: Troubleshoot a connection problem	✓	✓	✓
	T19: Troubleshoot a slow speed problem	✓	✓	✓
	T20: Determine how to get help/manual	✓	✓	✓
Wireless security	T21: Set up wireless security	✓	✓	✓
	T22: Set up advanced wireless setting - authentication type, rate, transmission rate, protection mode, frame burst, etc.	-	-	✓
Security alert	T23: Detect network intruders and computer viruses	-	✓	-
Routing	T24: Configure advanced routing, static routing	-	-	✓
Sharing	T25: Share a folder	-	✓	-
	T26: Share a printer	-	✓	-

While the users were performing the given tasks, I measured the effectiveness and efficiency of each task. To collect qualitative data, I directed the users to think-aloud while performing their tasks. If necessary, I asked the users questions for more qualitative data after they completed each task.

This evaluation was within-subjects evaluation. Each user performed selected tasks with each tool. To reduce the carry-over effect during the within-subject evaluation, some users started with Eden while others started with other tools. Users had a 10-minute instructional session for the evaluation process before the evaluation session. Manuals were available for users to use whenever they needed them.

After the evaluation was conducted, I asked the users to rank their preference order among the tools and give their opinions regarding the pros and cons of each tool.

7.5.4 Usability Evaluation Results

This section discusses the usability evaluation results. Section 7.5.4.1 discusses the users' tool preferences with an overall analysis of what caused these preferences. Then Section 7.5.4.2 – 7.5.4.6 discusses in detail how users performed tasks with the three tools for each management category.

7.5.4.1 Tool Preferences of the Participants

Seventeen out of the 20 participants preferred Eden over the other tools. Two users preferred a hybrid of Network Magic and Eden. One novice user preferred Network Magic. The traditional user interface, Linksys, was the least preferred choice of every user. Figure 38 shows the tool preferences of the users.

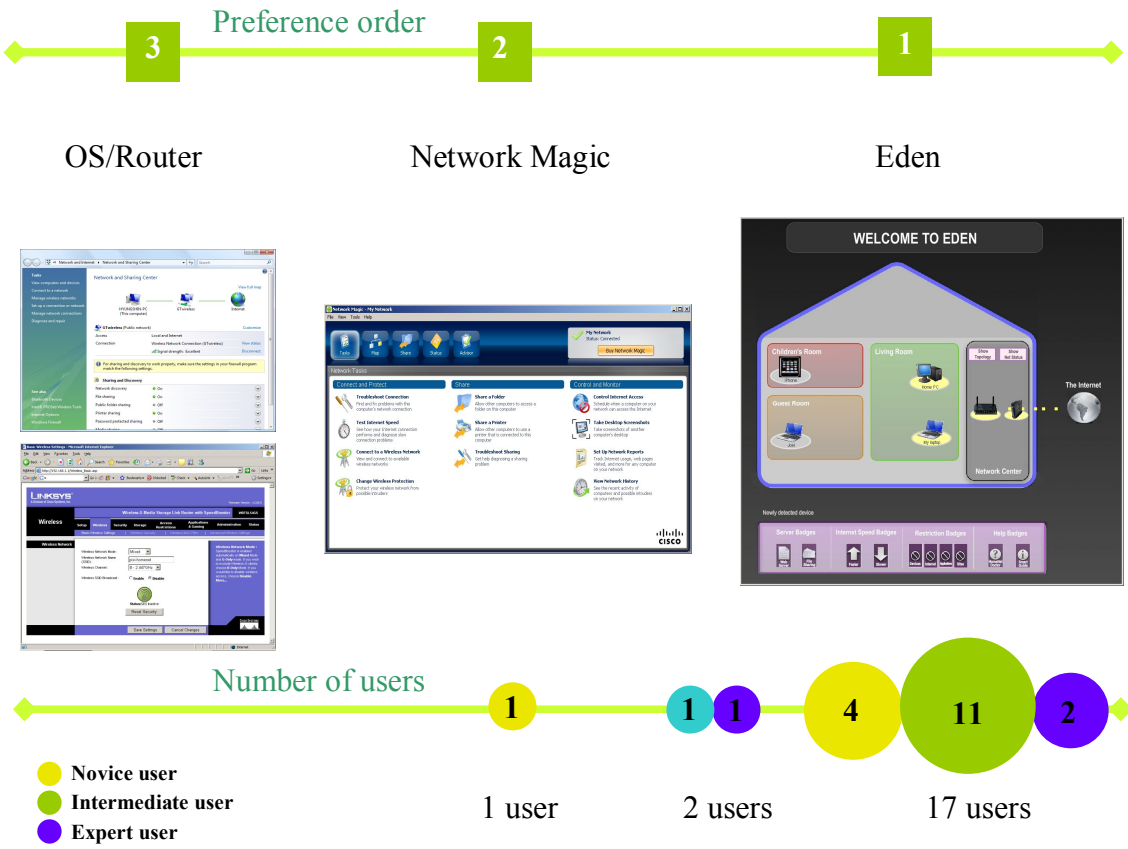


Figure 38: Tool preferences of the participants

The main feature that led to such tool preference came from the visual nature of the interface. The users preferred a more visual interface and a less technical,word-based interface. As P5 explained when describing his preference for Eden, Eden is very graphical, Linksys is entirely technical and word-based, and Network Magic is in the middle with some features that mirror Eden and some features that mirror Linksys in the sense that it provides a task-oriented interface and a visual map of devices, but all tasks are done though text-based menus.

> *"I don't like Linksys at all, and I love Eden. Eden is fabulous. Cisco's in the middle somewhere. It's not bad, but it's not great. It's difficult in the sense that they're taking steps towards usability, they always have "ways to go" type of things. They have nice features that mirror some of what Eden has. But they also have some features that mirror still what Linksys has. They have a ways to go yet to make it really understandable."(P5)*

What allowed all novice and intermediate users to perform management tasks so easily was the easy task activation based on drag-and-drop networking objects, affordance of networking functions, and the user-friendly task-oriented terminologies of Eden. For instance,

> *"It would be best for novice users. It's like a card game." (P3)*

> *"Eden is much easier because it's basically drag and drop and very straightforward." (P13)*

Eden's graphical user interface with its less networking-terminology based text-interface allowed all novice users to self-manage their home networks. For instance, P7 and P17, both pure novice users, had the following comments:

"I should be able to manage my home network with Eden. Network Magic is not understandable to me. I always prefer graphical representation and drag and drop". (P7)

"I guess I could (manage my network) if this (Eden) is my visual. I got the blocking. I can do troubleshooting with HomeNet Doctor." (P17)

In contrast, even though Network Magic tries to remove technical minutia (e.g. referring to devices by using names instead of IP or MAC addresses), Network Magic still was hard for many knowledgeable users, let alone for novice users. For instance, P6, an expert user, and P11 and P14, intermediate users, said,

"It's still hard, too many words. I don't like it at all. I think Eden is much much better. I don't see anything that you can not do with Eden. All tasks in Eden are better than Network Magic. I don't see any advantages over Eden." (P6)

"I don't like Network Magic because I have to read something that I don't understand". (P11)

"There are too many words that I don't understand." (P14)

However, one novice user, P20, preferred Network Magic over the other tools due to its rich text information. P20 thought the spatial metaphor of the Home very user-friendly and effective, though.

Some users mentioned the visual device map of Eden and thought it helped them learn about the home network through self-explanatory characteristics and metaphors. For instance, after about one hour of study with Eden, P2 and P20 stated,

"I feel like I (can) master home networking now. I learned how home networking works. I can imagine how home networking works in my mind. I learned what functionalities exist in the home network at a glance." (P2)

"Ahh.. this is the way the home network is working." (P20)

The spatial layout and task acivation of the Home metaphor was an advantage of Eden over the other tools, which provide either no graphic repersentation or just a tree representation of the home network.

"As more and more technologies are getting integrated into the home, I think it's very nice and will be much easier to use. Tomorrow or sometime, you could have a refrigerator in here that is also connected to the network. Smart table, and so on. So I think this one will evolve. And soon we will get into this kind of network that can evolve more and we can do tracking functionality if a person is carrying the laptop and the laptop is actually seen moving around house." (P6)

"Eden gives you the layout exactly what rooms the locations are. It tells which computer is whose computer." (P9)

"The space can give you a sense about which computer belongs to your home network and which one does not. If I have a lot of different computers, it would be hard to sense which one is mine and which ones are my friends. For instance, if the computer is in the living room, OK, this is my computer. If it is outside the house, OK, this is not my computer." (P11)

"I think Network Magic layout (tree) doesn't let you know that they are really your home network. But I imagine here (Eden) if one showed up here and the computer showed up connected out here or something, I first saw the newly connected device on there, I probably assume it was an outside computer whereas here you would just accept it as the computer that was connected or if your neighbors are stealing your Internet. If I had that one, I would use it because it's simple to recognize the home network. It doesn't look like it doesn't have anything that was frustrating." (P12)

"The Cisco network map doesn't much move things around and that really for a convenience sorting it's definitely good thing with Eden. I really like the ability to move the computers around. If I was running this home, I wouldn't probably set it up just by room, but I might try to set it up by some other criteria like machines that I consider more important. I'm assuming that initially have to correspond to rooms, though it doesn't make to (much) sense in that way. What machines are play machines or parents computers versus children's computers or something. Because it seems like I don't how much customization you are allowed on the rooms. but if you are allowed, people can customize individually in how they want. That I think is a big plus for people who want to be able to have things just the way they want." (P16)

The grouping functionality of the Home metpahor was a good point for some users, compared to the other tools, as P13 and P18 mentioned. The grouping functionality based on the Room metaphor discussed in Section 7.4.3 was found by users to be very useful in real situations.

"Compared to Eden, it doesn't seem like you can group." (P13)

"Just the way computers are grouped, you can group together. You know Home is something everybody familiar with. It's not threatening technically. It makes a lot of sense." (P18)

However, P10 mentioned the usability of the Home metaphor with the initial learning curve of the Home metaphor.

"Unless the users are explained that the computers in the Home represents the home network, users might not know exactly what to do with them. Let say if they are not very adventurous people and drag around or move around, they might not know. But once they knew that they can drag and drop, (the) Eden thing is much easier-to-use." (P10)

The integration of the visual device map of the devices and tasks was one of the most often mentioned good features of Eden over Network Magic. For instance,

"It is very difficult to say where am I going to start(with Network Magic). if my friend comes, I would block this guy. How do I block? task, map, shared folders, status, where do I start. It's crazy. Maybe task? Eden is much easier. a computer comes.. block.. That's it. So if I want to do troubleshooting connection, where is troubleshooting connection? if two computers are not sharing files, I have no idea it's connection problem or sharing problem. So do I go here or do I go there? But over here (Eden), I can see it's connection problem. I can see data flow. So it's probably sharing problem. So obviously graphical information makes more sense." (P6)

"I really like Eden. It's very good. For instance, I still need to go to the task menu (with Network Magic). For instance, if I find a problem with my computer, I would just drag the doctor and click the problem button, not go to the task panel. Maybe there are bunch of solutions and they will confuse me. HomeNet Doctor comes and says "now you have these kinds of choices", not go back to the task list." (P11)

"You don't have to navigate menus with Eden and that makes everything faster and easier for people who haven't used it before and don't really care to spend you know two hours learning how to do it they want to know. That's really good." (P16)

"For Magic, it's like a separate form you go to do, separate screen you go to perform that functions. It isn't like a single interface you can manage everything. You have to go to different screens to do different things. The visual layout here Eden tells what happens if you actually do these things." (P18)

Another good feature of Eden that was mentioned by all groups of users was that Eden had user-friendly, user-defined names for the devices. The importance of user-friendly names becomes more critical for novice or intermediate users. A considerable number of intermediate users did not have any idea what MAC addresses or IP addresses were.. This was the weakest point of the Linksys tool most often mentioned by all the participants. Interestingly, there were a considerable number of users who did not understand MAC addresses or IP addresses even among intermediate users.

"It's good to identify which computer is which." (P10)

"I like Eden. I don't know which number matches which computer if you just give me a number." (P11)

"I really don't like computers are identified by the ip address from a usability standpoint because you can memorize all the ip address of all the computers in your house. I think naming is really just up to what they name it." (P12)

"It's not better to deal with this ip or mac address." (P13)

"The network via Mac addresses or ip addresses because nobody in their home keeps stickers on their machines with their Mac addresses or anything like. Then you have to physically move around to do that anyway. The ability to change the computer's name, I could see that being friendly and useful to some people." (P16)

With regard to Network Magic, the participants liked the fact that Network Magic provides a task-oriented menu while hiding all detailed physical and low-level network information such as IP and MAC addresses. The task-oriented user interfaces of Eden and Network Magic were considered better than the Linksys one. However, many participants pointed out that the activation paradigm is not that different from the old style of the router or OS. The users also did not like that the activation paradigm does not provide a task-intergrated visual device map of the home network. Some participants added that it provides no visual traffic map for the whole home network and no visual feedback on task activation. Then, some users felt it is hard for them to use Network Magic.

7.5.4.2 Findings on Membership Management Tasks

Table 3 shows the tasks that each tool supports for membership management. Figure 39 and Figure 40 show the screenshots of Network Magic and OS/Router for adding a device to a wireless network.

Table 3: Membership management tasks

Management category	Management tasks	Eden	Network Magic	Router/ OS
Membership management	T1: Add a client device T2: Remove a client device T3: Configure DHCP server, client address range, DNS/DDNS setting	✓ ✓ -	✓ - -	✓ ✓ ✓

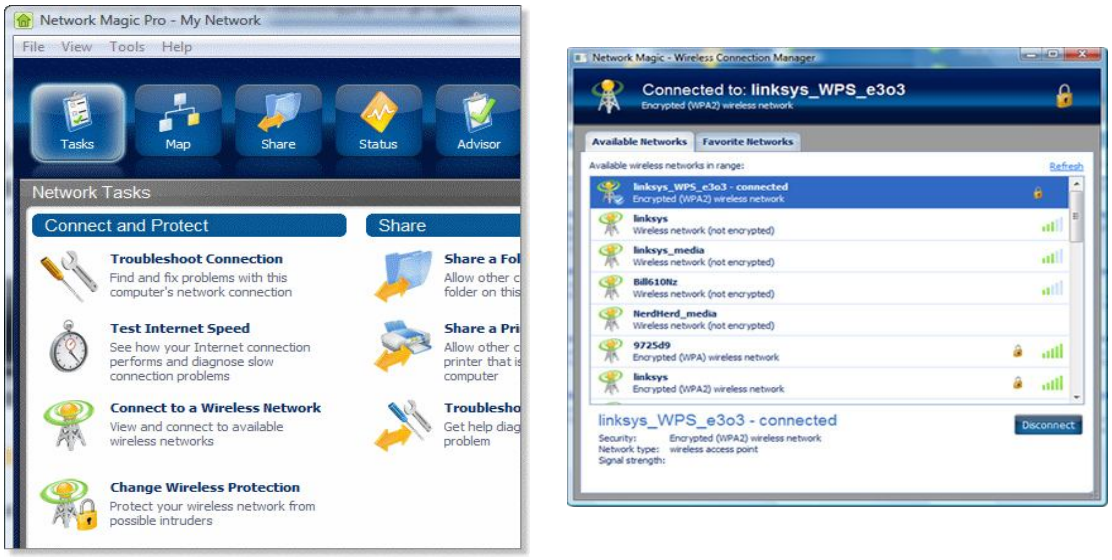


Figure 39: Screenshot of Network Magic for adding a device to the wireless network

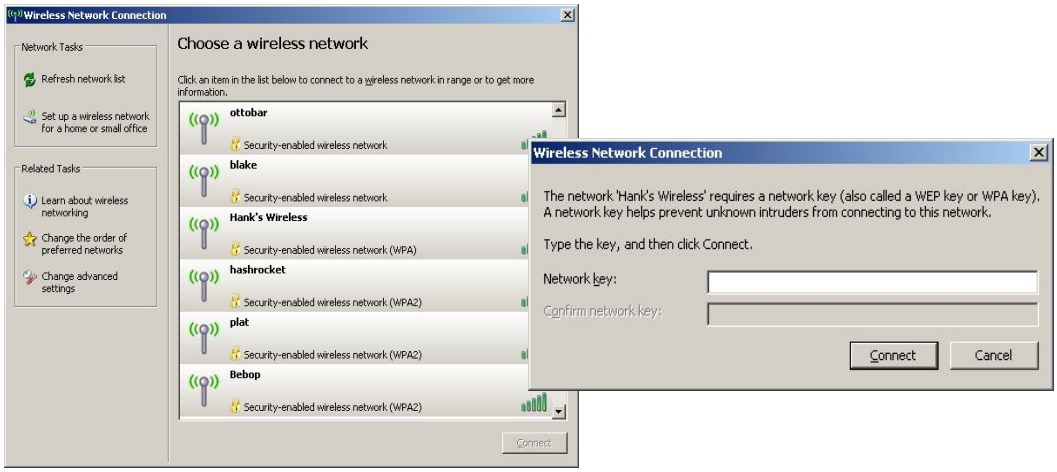


Figure 40: Screenshot of OS/Router for adding a device to the wireless network

Regardless of their technical knowledge level, nearly all the users preferred the graphical drag and drop style of Eden over the other text-based dialog box styles for adding and removing client devices. They also mentioned that visual feedback of membership of client devices is helpful. The more graphical the intereaction, the better the users liked it. They mentioned that Network Magic's procedural dialog-box based setup is very textual although it does not have numbers to refer a computer.

Eleven out of 15 intermediate and expert users (P1, P2, P3, P5, P8, P10, P11, P12, P13) strongly preferred Eden due to its efficiency over Network Magic and the OS wireless connection wizard. They all succeded in adding a device to the home network using all three tools, although the users took different amounts of time to add the device depending on the tool. Eden took the least amount of time, as expected, requiring only several seconds. while Network Magic and the OS wireless connection wizard took around 30 seconds on average. Here are some reasons users gave for their preferences of Eden over the other tools.

"Eden is very graphical. The Eden one is easiest because I can drag and drop. Adding the device via Cisco Network Magic might be ok. But it's not visual, I can't see the device that I'm dragging and dropping. So, it's nice to be able to see that device and see its name ahead of time as well. Network Magic is very textual. This does not have numbers, which is good, but I don't see a visual representation, which is always good to see what's going on. The OS one is very textual. This has lots of numbers too, which is even less useful most of the time. So the main difference is the visual nature of the interfaces." (P5)

"This OS one is a little bit tedious. Network Magic is fairly easy. Eden, you just have to drag and drop. It is very useful." (P13)

"This one, I feel like you have to have technical knowledge to use it. If you don't, you have to spend a lot of time to learn it. A lot of times, this if I'm setting up something quick, I don't really want to have the time of like finding the Mac address and blocking or allowing it. I think it's almost the time of efficiency of speed. If you can just drag something in, it's done and it's working. I think Eden is definitely the quickest and maybe the most intuitive way. This one (Network Magic) looks like kind of like a wizard step. I could see if that was like a poor things, i could see I could start getting overwhelmed." (P8)

"I prefer Eden because I can drag my computer into the house. I need visual information. I don't like network magic because I have to read something that I don't understand. So maybe it just makes sense for our daily life. You get the computer into the living room and it should be

connected to the network. (With network magic) I don't know which computer is mine and which computer is my friends, where the computer is. I don't know which router it is." (P11)

The most mentioned good points about Eden were 1) It provides graphical information, and 2) It hides all of the technical backend details.

"This one (Eden) is the simplest because you don't see the backend of it; it does all the backend for you. You just tell it, 'connect this computer to this router and does it'." (P12)

One expert user mentioned the technical point of Eden which is different from the wireless network infrastructure technology.

"Eden is simple to drag and drop from the perspective of UI. But in the technical level, it is a bit confusing. Currently, client devices detect the router, but in Eden, the router detects client devices. For instance, when visitors come, routers should detect the visitors." (P3)

It was found that users consider any graphical information very helpful to them. Many users pointed that that the router and the OS tool does not provide any grpahical informaiton about the network topology or task activation.

"(With OS/Router) You don't have a graphical interface. From a client point of view, if I want to connect to the specific router, I would just pick which one I want to connect and then I would just click one." (P13)

For Task 3, DHCP and DNS configurations, two users who had previously configured DHCP and DNS settings had different responses regarding their usefulness.

"For the first time, I used to use these things. But later, I do not deal with them at all. All I use is MAC filtering." (P3)

"I customize the IP address. I believed that it's safer if I use something different than the default one. I just feel like that regardless of the real technology." (P4)

7.5.4.3 Findings on Access Control Tasks

Table 4 shows the tasks that each tool supports for access control. Figure 41 and Figure 42 show the access controls for Network Magic and OS/Router.

Table 4: Access control tasks

Management category	Management tasks	Eden	Network Magic	Router/ OS
Access control	T4: Block Internet access for client devices	✓	✓	✓
	T5: Block applications	✓	-	✓
	T6: Block websites	✓	-	✓
	T7: Designate a server device (web/file server)	✓	-	✓
	T8: Block internal devices	✓	-	-
	T9: Block anonymous Internet requests, filter Internet NAT direction/multicast	-	-	✓

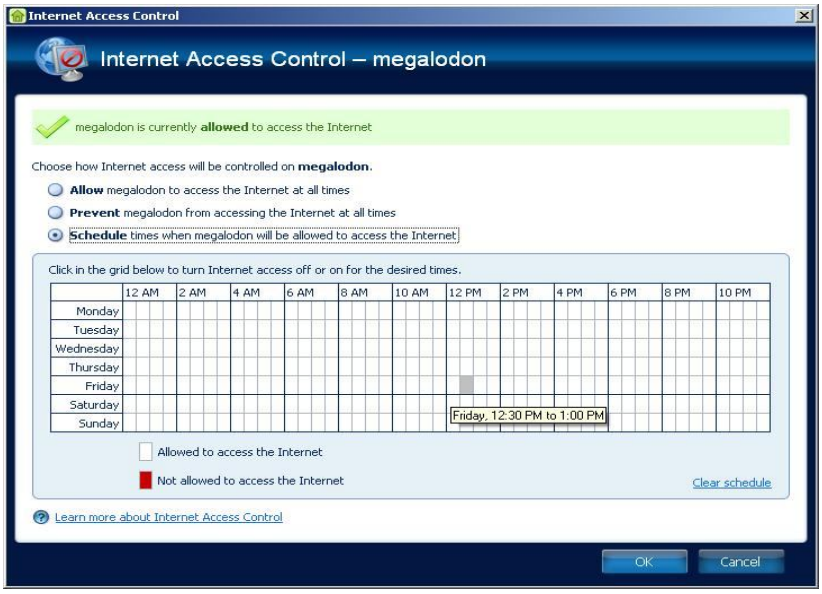


Figure 41: Screenshot of Network Magic's Internet access control for a device

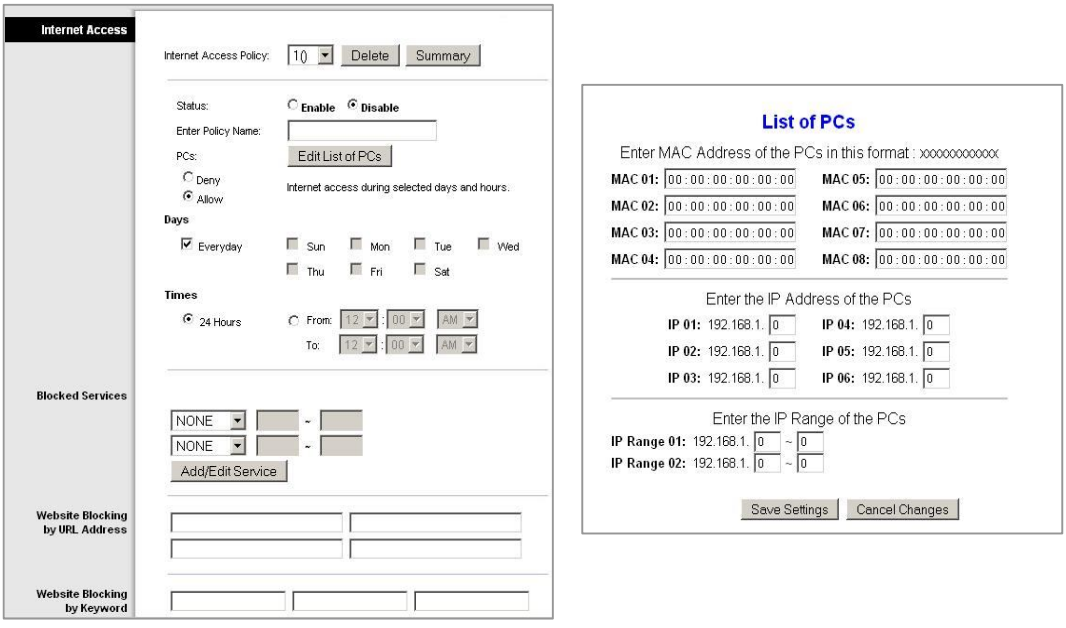


Figure 42: Screenshot of Router's Internet and website access control

Eden and the router provide various options while Network Magic provides only Internet access control. As discussed in the metaphor evaluation section (Section 7.4), access control was the primary concern for many people, especially for parents with children.

Eight users out of 13 strongly preferred Eden over the other tools for Internet access control regardless of their technical level of knowledge of networking. The main reasons for this preference (, as expressed by the participants,) was the visiblity of a device and the visiblity of function and feedback.

> *"Network Magic and Eden are all doable, but Eden is easier than Network Magic because it's just requires drag and drop while Network Magic requires to go though several steps." (P1)*

> *"Eden is the best because all devices are graphically visible and options are visible; all users need to do is to drag options onto device icons. Network Magic is the second best. It requires figuring out client devices by the computer name, but it takes several steps to go though in a dialog box, not directly on the device map like Eden. Router is the worst, because it requires users to know MAC and IP address. Users need to find out (the) MAC address of devices to set the block configuration." (P2)*

> *"It gives a little badge. It shows a sign of functions. ... It shows that (there are) some restrictions on the device. So (the) icon is useful." (P4)*

> *"This (router) is hard clearly because you have to know stuff like what you are blocking and it's not visual. So it's recall versus recognition to a certain degree where it's nice to be able to just recognize on Eden that I can take an icon and drag it to a computer and then it works. Versus I*

have to recall a whole bunch of information to be able to use that (router) interface. Cisco again is kind of in the middle. It seems like you can allow, prevent, schedule too for some device. But, if you choose that device, it may not be clear what that device is, where it exists, stuff like that. Eden helps out with that." (P5)

Meanwhile, three users (P3, P10, P13) did not have specific preferences between Eden and Network Magic. They liked both Eden and Network Magic. One user (P12) preferred Network Magic over the other tools.

"I imagine Linksys is harder. I have to mess around with it. Network Magic and Eden are definitely easier than Linksys. Network Magic is fairly simple because it's just right there, and Eden is nice with its little buttons that you drag around. I prefer this type of setup (Network Magic). I know Eden would work a lot better for my family because they take more time navigating than I do. Eden is definitely easier to use." (P12)

Some users liked Eden because of its efficiency, as P8, an expert user, mentioned.

"Eden is the quickest; you almost feel like 'Ok, I blocked the website. I did what I wanted to do. I'm done, and I'm happy.' But this you kind of have to put some thought into, like 'Ok, if I want to have a schedule, do I want to have a schedule or do I want to block the Internet. It's more choices and more processing." (P12)

The physical layout of the Home in Eden helped users figure out the device that users wanted to block. For instance, P11 stated,

"(With Network Magic) I don't know which one I should block. Maybe I block all one because I don't know which one is which one. I don't want technical details. I just need to block the computer." (P11)

Four users, P4, P8, P10, and P16, emphasized their need for time-scheduled Internet access control, which Eden does not support at this point, but the other tools do. For instance, P10 mentioned,

"Schedule access is very cool because kids come home at 3 and you might be using this computer before the kids come home. You don't want kids to use the computer like after 3." (P10)

All 13 users agreed that the router tool was least easy to use in terms of usabiltiy. Even intermediate users, P1 and P10, failed to do access control successfully using the router tool because they did not understand the MAC address. The biggest problem that they had with the router was, again, naming issues.

"Router is the worst, because it requires users to know MAC and IP address(es). Users need to find out the MAC address of devices to set the block configuration." (P2)

"The Linksys one is the worst. Too many buttons, texts to go out, technical words, no way to see which devices exist unless you go to each list of PC. (P4)

"It seems to offer a lot of customization, type specification or what you are doing, but it seems you have to control every machine via a Mac address rather than friendly computer names. So that's a big disadvantage." (P16)

The physical layout of the Home in Eden helped users figure out the device that they wanted to block. One user had difficulty figuring out devices by the name assigned to the comptuer. Therefore, unless this user had known that computer name, this user would not have known which one should be blocked.

> *"(With Network magic) I don't know which one I should block. Maybe I block all one because I don't know which one is which one. I don't want technical details. I just need to block the computer." (P11)*

As discussed in the metaphor evaluation section (Section 7.4), multiple levels of access controls – access control at the router for the whole nework, at the room for a group of devices, and at the computer for an individual comptuer – was another aspect of Eden that users liked over the other tools.

> *"I like having the different separations because you don't have to go find them. You can just do them right here. And I do like having groups, you know, you can rename the groups, and so how you set them up, you can group together control. I think that would be very useful on a network, especially if you had a lot of computers." (P12)*

One user, P16, addressed the need for authentication for access control and other functions in Eden.

> *"You just moved the icon. That was definitely the easiest of settings. I'm a little bit confused though because every computer can use Eden. It seems like somebody who's blocked from the Internet could just go back on and move the block Internet icon back off and be able to access again. That would be the disadvantage of the setup. It seems like you need some administrative access control, or else anything I do for my child computer to limit access, they can just go on Eden and undo." (P16)*

Authentication control is definitely necessary when managing the home network, and at this point Eden does not take it into consideration because currently Eden focuses only on network managmeent alone. However, in the future, Eden should provide some way for authentication control, such as a password scheme.

7.5.4.4 Findings on Network Monitoring Tasks

Table 5 shows the tasks that each tool supports for network monitoring. Figure 43 and Figure 44 show the screenshots of Network Magic and OS/Router for access control.

Table 5: Network monitoring tasks supported by the three tools

Management category	Management Tasks	Eden	Network Magic	Router/ OS
Network monitoring	T10: Check the connectivity status of a device	✓	✓	✓
	T11: Check the network speed of a client device	✓	✓	✓
	T12: Check the network speed of the home network	✓	-	-
	T13: Determine network bottleneck points	✓	-	-
	T14: Show the histories of Internet usage, visited websites, applications	-	✓	-

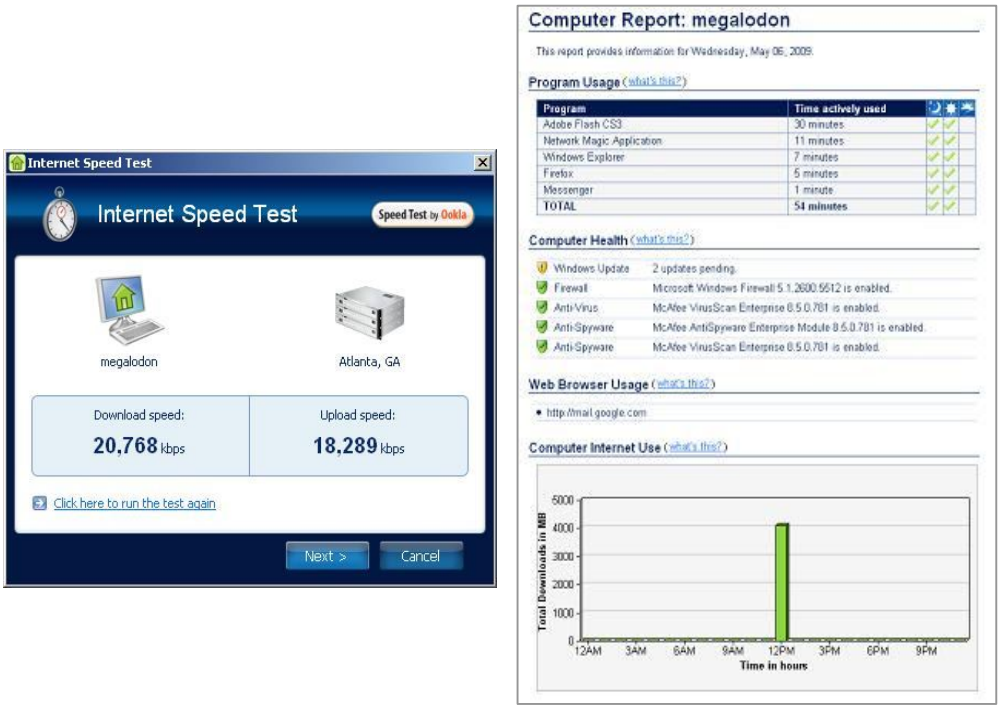


Figure 43: Screenshot of network speed of an individual device (left) and application/web/Internet usage history (right) of Network Magic

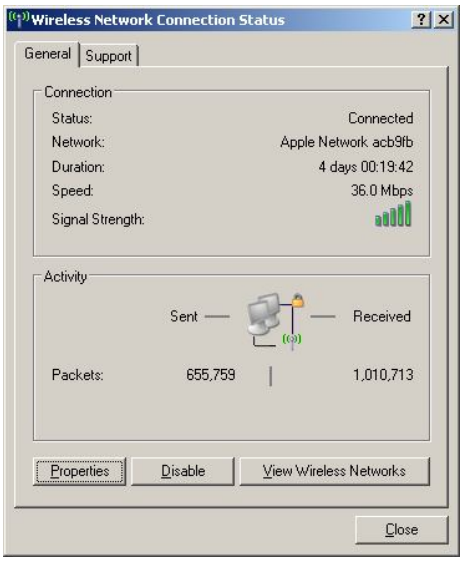


Figure 44: Screenshot of network speed of an individual device of OS

The main difference between Eden and the other tools is that Eden shows the whole map of the network speed while the other tools show only the individual computer's network speed. P1, P2, P11, P12, and P13 mentioned this point as the primary advantage of Eden over other tools.

> *"I do not know how to check up on the total home network speed. Eden is especially easy to know the total network status of the network map. Network Magic does not show the total status map; it shows individual ones." (P2)*

> *"(With Network Magic) I just see one device. I cannot compare devices. Even if I compare them, I need to spend some time because I need to know that this speed is high speed or low speed. (With) Eden, I can know that this computer is high speed and this computer is low speed." (P11)*

> *"Eden is the speed of individual computer plus overall. It has extra information. I guess one computer is slowing down for some reason and then I could have a clue. Network Magic seems to be overall." (P13)*

Users preferred the graphical representation of Eden and Network Magic over the text information of the Network Magic and OS tools.

> *"(With Eden) I automatically see all. For certain things, I prefer graphical representation. Network Magic is a pretty good interface; upload and download speed is good." (P10)*

One user mentioned a confusing point about Network Magic.

"For Cisco, it shows download and upload. But I'm not sure if it's actual download speed or upload speed or available download speed or upload speed." (P4)

7.5.4.5 Findings on Resource Management Tasks

Table 6 shows the tasks that each tool supports for QoS managmeent. Figure 45 shows the screenshots of OS/Router for QoS management. Network Magic does not support QoS management.

Table 6: Resource management tasks

Management category	Management tasks	Eden	Network Magic	Router/ OS
Resource management	T15: Assign high speed priority for a device T16: Assign high speed priority for an application T17: Assign high speed priority for an Ethernet port	✓ - -	- - -	✓ ✓ ✓

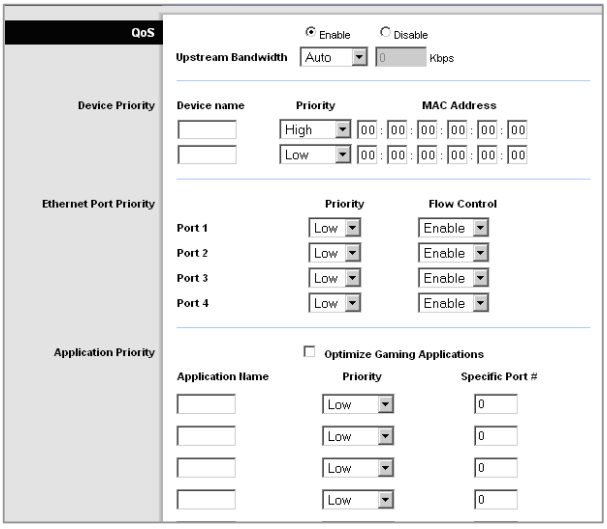


Figure 45: Screenshot of network speed of an individual device of OS

I asked 7 intermediate and expert users to perform Task 15. With the router tool, 3 (P2, P4, P12) out of 7 users succeeded at assigning high priority to a device using the router interface while four users (P1, P10, P11, P13) failed. The biggest problem of the router's QoS control was naming issues for the task itself and a device. For instance, P10 did not understand the MAC address and thus failed to assign a priority for a specific device. P11 didn't understand the term, "Quality of Service" of the router interface, saying

"I'm not comfortable with these words". (P11)

All 7 users prefered Eden over the router interface for the following reasons.

"Linksys could be trouble if you don't know the exact name of the application name. This has more steps to go through to assign a priority. But here (Eden) you just drag the high priority to it." (P4)

"It (Eden) keeps you from doing the backend work, not forcing you to find the MAC address. Because I can see that would be hard for a lot of people, finding the MAC address. I think with this (the router interface) they're assuming you can get to the router and you know all this stuff; then it's not always the case." (P12)

7.5.4.6 Help/troubleshooting

Table 7 shows the tasks that each tool supports for help/troubleshooting. Figure 46 and Figure 47 show the screenshots of Network Magic and OS/Router.

Table 7: Help/troubleshooting tasks

Management category	Management tasks	Eden	Network Magic	Router/ OS
Help/ Troubleshooting	T18: Troubleshoot a connection problem T19: Troubleshoot a slow speed problem T20: Determine how to get help/manual	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓

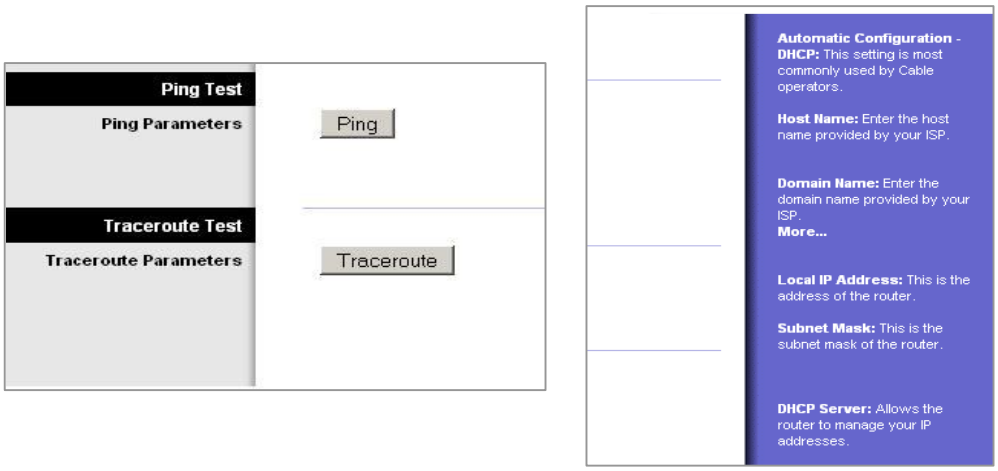


Figure 46: Screenshot of network diagnosis and help of OS/Router

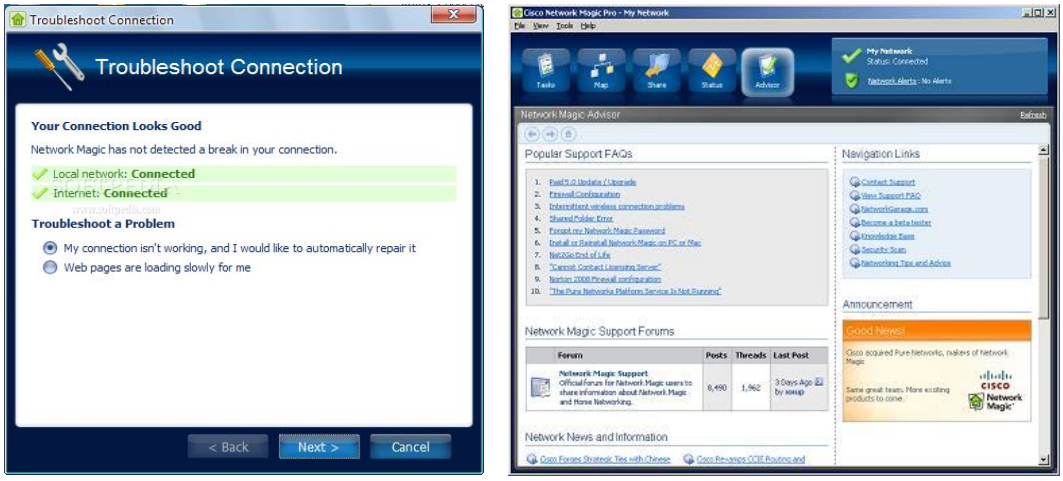


Figure 47: Screenshot of network diagnose and help of Network Magic

Again, the OS/Router was the most difficult for all users for help/troubleshooting as well. Eden and Network Magic were doable for users. The folwloing are some comments on the tools.

> *"(With)Ping, you need to know the IP address. HomeNet Doctor, you don't need to know the low level info (IP) for debugging. HomeNet Doctor is much more convenient than command-line tools. Network Magic… it needs to show graphically where the problem occurs. Eden shows graphically the map while Network Magic separates the device maps and the device." (P2)*

> *"For existing tools, to use it, users need to know what the problem sources are technically, then figure out the problem." (P3)*

7.6 Discussion on Metaphor Breakdowns

In this section, I discuss the metaphor breakdowns that arose during the user interface metaphor evaluation. The user interface metaphor evaluation results were discussed in Section 7.4.3.

For each metaphor breakdown, I first present a brief description of the metaphor breakdown. I then discuss the root causes of the metaphor breakdown I finally suggest some alternatives for how these metaphor breakdowns might be avoided in future designs.

7.6.1 Home Metaphor

The Home is a spatial concept that represents an abstract, invisible home network. It provides a physical mapping ("location") between actual devices in the user's home and devices on the on-screen Home. At the same time, it provides a visible logical mapping ("connection") between the devices "on" the home network and the devices "not on" the home network. In other words, the Home serves as a visible container for the devices on the home network, and allows users to add or remove a device to or from the home network by dragging the device inside or outside the Home, respectively.

While most of the study participants recognized the intended meaning of the spatial concept represented by the Home, several users were confused.

- **Devices outside the Home**

Two users (P2, P3) were confused about the meaning of the devices outside the Home. They believed that these devices were likely wirelessly connected devices sitting outside the Home, for example, in the yard or on the deck of the home. P2 was an intermediate user, and P3 was an expert user.

The reason for the confusion is that the Home tries to convey simultaneously both the physical and logical mapping for the devices. However, in the current Home representation, the physical mapping (of device to room) and logical mapping (determining whether or not the device is on the home network) apply only to the devices physically inside the user's home. The current Home metaphor only applies the logical mapping to devices outside the home. In other words, devices outside the home are logically "off" the home network, but this says nothing about their physical placement: the devices (represented by the icons) outside the Home are not necessarily intended to physically map to the actual locations of users' devices.

These two users interpreted the physical and logical mappings as applying to both the devices represented inside the Home as well as the ones represented outside the Home. It must be concluded, therefore, that there is a potential for users to become confused as a result of the discrepancies between logical and physical containment implied by this model (participants noted, however, that the presence of topology lines between the router and individual devices helped to clarify these relationships).

Several approaches would help mediate this confusion. One simple approach, as shown in Figure 48, is to have graphical symbols around the devices inside the Home. This graphical annotation would indicate whether the devices are wirelessly connected or connected through a cable. This added representation would thus indicate to users that that devices outside the House are neither wirelessly connected nor connected through a

Figure 48: Graphical symbols for connection media

cable.

Another approach may be to extend the physical containment metaphor to the exterior of the house, for example, to allow users add a Yard area if they have a yard at their home, just as they are able to create, rename, or delete a Room according to their real home structure. Then the physical Home boundary should be extended up into the Yard. This may help users to distinguish between devices that are physically outside (such as on a yard or deck) and are connected to the home network, from those that are both logically and physically outside the home network. Thus, this design would provide both physical and logical mappings for every device connected to the home network, regardless of whether its position is inside or outside the home.

However, results from the study suggest that many users would be unlikely to place wireless devices in the Yard even though they use wireless devices sometimes in the yard. This is because most of the study participants in the Eden user interface metaphor study tended to place mobile devices in an ownership-based manner (e.g. Bob's room if it's Bob's device).

- **Removing a device from the home network**

Two users (P7, P9) preferred leaving the device inside the Home in order to remove it from the home network rather than dragging it outside the Home. Especially to P7, a novice user, it did not make sense to have the computer represented as being outside the Home unless, as he commented, he kept the device physically outside the Home. P9 was an intermediate user, but one with little technical knowledge of networking. This user also tended to privilege the physical view of the home network.

This metaphor breakdown results from a reason similar to the one described in the previous section, "Devices outside the Home". The Home is not intended to provide a physical mapping for devices that are not actually on the home network. It provides only

a logical mapping for them. As a result, dragging the device outside the Home does not make sense to some users while they still have those devices physically inside the Home.

Several approaches would help deal with this metaphor breakdown. One simple approach is to allow users to remove a device from the home network with a "remove" option while still leaving the device inside the Home. Then, as P7 suggested, Eden can use a different background color scheme to distinguish between the member devices and non-member devices in the Home. For instance, the device's background could become grayed out when it is removed from the home network to signify that it is no longer a member of the home network. The device's background could become light-gray when it is just inactive but still physically a member of the home network. The device background could become yellow when it is currently active on the home network.

Another approach would be to separate the Room into two spaces for the member device and the non-member device. For instance, when a device is removed from the home network and is no longer a member of the home network, the device could be placed in the left side of the Room. When the device is just inactive but still a member of the home network, the device could be placed in the right side of the Room. Eden could also allow users to create another visual image (e.g. "device closet") in the Room for the non-member device. This approach, however, could potentially raise another downside of the user interface metaphor, in that it suggests a too literal adoption of the metaphor that introduces details that may overburden users.

Another approach is to have a separate Room (e.g. "old device room") designated for non-member devices. However, in that case, the physical mapping of the Room metaphor might break down since the separate Room designated for those devices would be a virtual room existing only in the Home abstraction and not in the actual home.

All of the mentioned approaches, however, require a slight change to the original Home metaphor, which serves as a logical container only for member devices. Further, they can raise another metaphor breakdown. For instance, in the case of a visitor's device,

the visitor's device is not only "removed from the home network" but also physically moved outside the user's real house. To solve this breakdown, it may be possible to let users decide whether they want to leave non-member devices inside the Home or if they want to drag non-member devices outside the Home.

- **Topology line as a clear indication of a device's membership**

Many of the metaphorical breakdowns mentioned here were mitigated when users used the topology display. The topology overlayed on top of the Home helped mediate the metaphor breakdowns of the Home because it provided a more explicit indication of a device's membership. This was one of the main reasons that Eden integrated the topology of the tree representation in to the spatial representation.

7.6.2 Badge Metaphor

Sixteen users immediately used the Badges appropriately during the first trial. However, several users (P2, P4, P5, P16) did not grasp the Badge metaphor during the first trial, although they quickly got the concept of the Badge after several trials and errors.

This metaphor breakdown seemd to result from their previous experiences with existing network management tools or other computer applications. For intance, P2, an intermediate user, tried to find the IP address of a target device when she was asked to block a certain website for the target device. This was because she was used to configuring a network setting of a device using the device's IP address. Similarly, P5, an intermediate user, expected that some menu would pop out when he clicked a Badge. This was because that was the way that he used to experience existing menu- or wizard-based network management tools.

However, when these four users understood the Badge concept after a while, they preferred the Badge approach over the approach of existing tools due to the visiblity and ease of dragging and dropping. The remaining 16 users preferred the Badge approach as well. This indicates that the Badge concept for the networking settings works well, and was easily understood by most users.

As discussed above, the badge metaphor breakdown resulted from the users' previous interaction experiences rather than from the conceptual breakdown of the way that the Badge works. These results suggest that some additional feedback and affordances around the Badge interaction may be helpful for users (the current implementation of Eden provides very limited support in this area). For example, providing feedback when a badge is dragged over a potential target may indicate that it can be attached there; likewise, tooltips on badges that indicate they are draggable may help novice users learn their functionality more quickly.

- **Room-based control for a group of devices**

This was also more a design issue than a metaphorical issue. The Room did not provide an explicit affordance indicating that badges could be attached at the room level.

Several new designs may help to solve this problem. One design is to assign a small Badge area for each Room, as shown in Figure 49. A user drags Badges to the small Badge area. This design can be applied for individual devices to give a more explicit cue for them. Each individual device has a small Badge area around itself. Then users drag a Badge into this Badge area. This will increase the visual affordance for individual devices.

Figure 49: Badge areas associated with a Room and a device

Another approach would be to make a Room's boundary or all devices within the Room highlighted as a Badge comes inside the Room. This will allow users to recognize that the Badge is being applied to all the devices within the Room.

- **Placing the Badge on the link between the router and the target device instead of directly on the target device**

Three users (P8, P15, P17) put Badges on the link between the router and the target device instead of directly on the target device. For instance, P8, an expert user, placed an "Internet Speed" Badge on the pathway between the target device and the router. This user tended to focus more on the flow path of data rather than the target device since controlling Internet speed is the same thing as controlling the data flow and the data flow is visually represented on top of the link between the router and the target device.

P15 and P17 were novice users. Even though they did not have prior knowledge about network traffic flow, they saw the visual traffic flow in Eden and tended to think in the same way that P8 did.

Several design approaches can deal with this confusion. One way is to have Badges applicable to the link as well as to the target device, as shown in Figure 50.

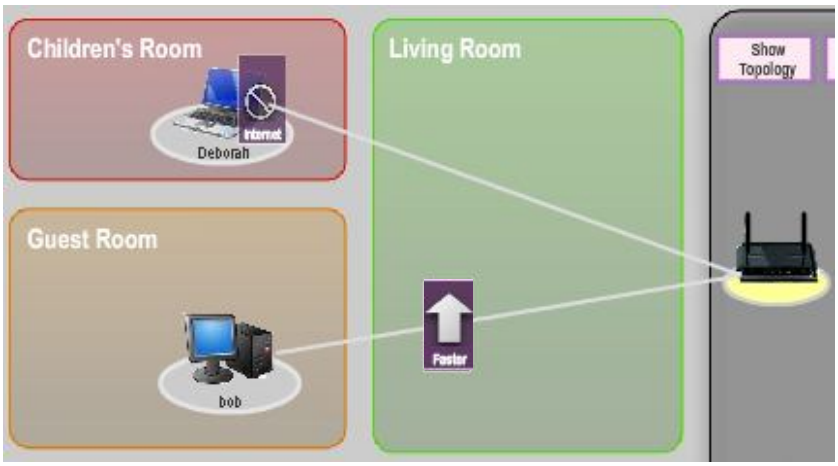


Figure 50: Badges on the link as well as on the target device

However, this design approach will cause inconsistency among individual device-based, Room-based, and router-based Badge applications. For instance, a Room does not have any link between the router and itself on which a Badge can be placed. Furthermore, some Badges conceptually match only the target device, not the link. For instance, a "File Share" Badge is conceptually associated with a target device, not with a link.

Another design is to keep the current approach while providing some automatic change of the Badge to reinforce the intended relationships. For example, when a user places a Badge on the link between the router and a target device, the Badge could automatically move to the target device, reinforcing the conceptual model that badges can be associated with individual devices.

- **Too many Badges on a device**

This was a visual design issue rather than a metaphorical issue. Too many Badges on a device could entirely hide the target device.

This issue could be dealt with in several ways. One is to make the Badge minimized once it is applied to a target device. When the cursor moves over the Badge, it goes back to its original size so that a user can recognize which Badge the device is associated with, much like the "fisheye" effect in the MacOS X dock. When the cursor moves away from the Badge, the Badge becomes minimized.

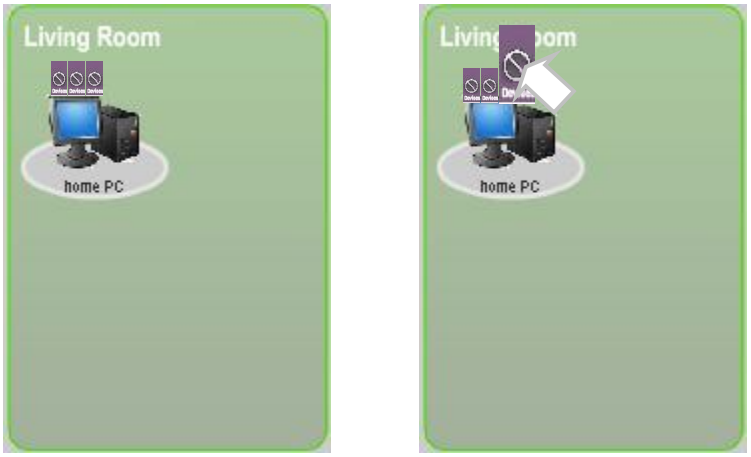


Figure 51: A minimized Badge (left) and an original-size Badge (right)

This approach will still provide at-a-glance user awareness for all Badges associated with the target device. However, it is not a scalable solution. It can still have the same problem if the number of Badges increases.

Another approach, as shown in Figure 52, is to have a visual cue for all Badges. When a user clicks the visual cue, all Badges pop out. This approach will be scalable regardless of the number of Badges associated with the target device. However, it will not provide the same degree of at-a-glance awareness for the Badges associated with the target device.

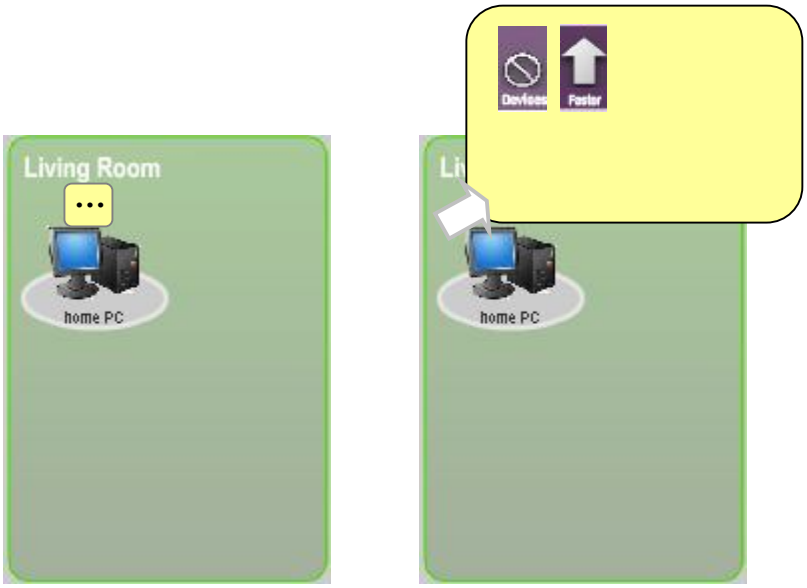


Figure 52: Minimized Badges (left) and Original-size Badges (right)

CHAPTER 8

DISCUSSION AND CONCLUSION

This chapter serves four purposes. First, it revisits my research statement and the research questions yielded from the research statement. It then discusses whether the research statement has been proven correct or not by answering the research questions. Second, it discusses design implications for a management tool generalized through this research. Third, it discusses potential areas for research found during the Eden evaluation. Lastly, it concludes this dissertation with a summary of the dissertation's contributions.

8.1 Answer to Research Statement and Research Questions

My research statement was:

> "A home network management system based on direct manipulation can simplify home network management and thus increase the usability of the home network for users who have either only informal or no technical knowledge of networking"

I attempted to prove the research statement through the by addressing the following research questions:

Q1. What visual representation and task activation paradigm would be effective for users who have either only informal or no technical knowledge of networking?

Q2. Does a new interaction model based on direct manipulation enrich users with no technical knowledge of networking and help them begin to

understand the conceptual model and functions of the home network so that they can carry out basic management?

Q3. Does a new interaction model based on direct manipulation help users with informal knowledge of networking understand the conceptual model and functions of the home network and better perform tasks in terms of effectiveness and efficiency, compared to the network management tools they have used in the past?

I was able to answer the research question, Q1, through two steps – the formative study and the Eden user interface evaluation. Through the formative study, I was directed toward the new possibility of a more visual home network representation that utilizes the spacial concept of a real Home in addition to the traditional tree representation, and the new possiblity of a drag-and-drop based task activation paradigm. The spatial concept of a real Home was familiar and understandable to all groups of users, including novice, intermdiate, and expert network users. The drag-and-drop based task activation also proved more familiar and easier to use than other methods such as a menu or dialog box.

The formative study results informed the final system of the visual representation of the home network and task activation paradigm. Through the Eden user interface evaluation, I proved that the spatial concept, the other user interface metaphors, and the drag-and-drop based task acivation paradigm worked well in terms of understandability and usablity for users with little or no technical knowledge of networking as well as for skilled network users.

I found answers to research questions Q2 and Q3 through the Eden user interface and usabilty evaluation. The Eden user interface evaluation showed that Eden helped many of the network novice and intermediate users learn, for the first time, the conceptual and operational models of the home network via the graphical device map

overlaid with the topology and traffic flow of the Link-Pipe. In addition, the visual graphical objects for digital controls also helped users grasp what functions exist for the home network. The usablity evaluation study showed that Eden, which is based on direct manipulation, performed better than the existing home network management tools and that the majority of the study participants preferred Eden for future use over existing management tools. In particular, very novice network users were found to be able to perform management tasks with Eden. Many intermediate users were also found to perform tasks with Eden more effectively and efficiently than with existing management tools. This indicates that Eden ultimately increased the user's ability to manage the home network.

8.2 Research Potentials

This section discusses the research potential found during the evaluation.

Access Control. It was interesting to find out that access control was a very primary concern to users, especially to users who have children. Internet and website access control was a fundamental concern to parents.

For instance, P2, a mother of an 11 year-old daughter, had no idea how to do website access control. At the time of the study, she had never installed any website access control software. Therefore, what she did for parental control was to keep checking on her daughter frequently when her daughter stayed in front of the computer for a long time. When P2 used Eden, she liked most the functions of access control for websites. As the mom of a 5^{th} grade daughter, she also suggested that it would be great if Eden provided a default list of parentally controlled-websites that could be applicable to children who were the age of 5^{th} graders. She added that website access control was the primary concern of the home network among the parents of her daughter's friends.

P9, an intermediate user and a mother of three children, did not know how to block out Internet for a family computer for her kids. Therefore, she put a family desktop inside her room so that she can manage that the kids won't be on it late at night or only use it for school purposes, sometimes, educational games. This user also liked the ease of Eden's access control.

> *"Currently, I don't do access control because I don't know how to do that. I'm not knowledgable about how to block out his (Internet access) time only. I would do that if I know how to do that. Because sometimes he likes wrestling, he goes online, he watches wrestling games. I don't want him to watch that too much. (If I block the wrestling game at the router) I would think not because this (the map of the devices) tells the information. (Block wrestling game for kids - immediately drag the badge icon) this is good. Before I didn't know how to do it." (P9)*

Access control for data among devices in the local network was important to many users as well. This function, supported under the name of "Block internal devices" in Eden, is currently inaccessible to all groups of users due to its diffculty. For instance, P1, an intermediate user, has not used shared folders because she could not trust the home network. She thinks it is risky to allow computers to share files. To her, the home network is just for sharing a single Internet connection, not for sharing data among devices in the local network. Instead, she has used memory storage hardware to share files among devices in the local network. She said that if there are methods to ensure data privacy, she would use shared folders. For P1, access control for internal devices was the primary concern. P11, another intermediate user, also worried about data privacy.

> *"I wanted to set up some security on my computer or maybe block some at the router, but I don't know how to do it." (P11)*

The same concern was found in the formative study as described in Section 4.2.2. One intermediate user worried about data privacy among devices in the local network in the case of shared folders and wanted to have some access control mechanism for that.

P6, an expert user, wanted to distinguish between his own devices and visitor's devices to protect data in his own devices. This user also suggested a more fine-grained device access control at the data and device levels.

> *"How about block file access? If a friend of mine comes and I just want to block file access so that this guy cannot access any files on that. I'd also like to allow printer access as soon as this guy comes in, you know sometimes friends come to your Home and are doing a project together and this guy needs to print to a printer. I would like to say - allow printer- and that's all I want to give that guy, allow printer." (P6)*

Access control was not necessarily used only to protect data or devices from unpermitted access. For some users, access control could be used for other purposes. P7 has a 17-year old daughter, a high school student. He did not control access for Internet or websites, but suggested that access control could be used for punishment.

> *"What if I want to block an email address or text messaging for one kid. I would never do that (Internet or website access control) because I trust her with her own judgment. She is a good girl. If she goes to some nasty web sites, that's her business. I wouldn't do that. I wouldn't waste my time. But I was wondering, if it could be that specific, as a parent, there is a parent that that might do that as punishment. Like a child was late last night; therefore we block her access to messaging for the next two weeks or something like that." (P7)*

P7 also implied social aspects for this kind of access control.

"Badges could be different colors. There could be pink badges for mom and blue badges for dad that could actually say who did the blocking. So dad knows that the daugeter did something bad, so dad blocks it. Then mom comes to the computer, Internet, I mean networking graphics. Oh why did Dad block you. Now mom and the daughter have to have a conversation." (P7)

As discussed, access control was the primary concern for users, including parents with children. So far, access control has been dealt with mostly from the perspective of network intrusion detection and remote access control in the networking community. Household-oriented access control has not been addressed that much yet in the networking and HCI communities. There are some commercial tools such as Net Nanny[13] that help users do parental control for safer Internet activities. Nonetheless, many users have usability problems with access control due either to the technical difficulty or to the user's lack of knowledge of tools. Therefore, I believe there is research potential for home-centered access control – to examine how residential users do access control, to examine what needs they have with regard to access control, and to provide solutions for them.

User-Driven QoS. It was interesting to find out the needs of user-driven QoS as well. Originally, user-driven QoS was included in Eden since it was found to be useful to some users in the formative study. Before the formative study, users had no idea about the user-driven QoS function. As in the formative study, only several users had known

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[13] http://www.netnanny.com/

that they could assign user-driven QoS for high speed in Test Session 1. However, when users knew they could do user-driven QoS control through Eden, many users showed an interest in user-driven Qos. The following are some user comments on user-driven QoS.

> *"There are a lot of times where like one computer has a high speed rather than another computer. And if it is easy to do, I would do it more often than if it's not easy to do. So there are times like playstation is downloading or updating something and I want to go faster rather than slower. So in that case, I probably drag that. Or my fiancé or I are doing something really data-intensive on the web. We will probably give high priority to that computer rather than another one." (P5)*

> *"I think this is a nice idea to see high speed. I want good speed. This is pretty nice. I like it. Le's say, if I am doing webcam and my kids are watching a movie from the Internet, I would like to say, 'turn theirs down.' Sometimes, my wife is talking on the phone. I'm doing an Internet download. She uses VoIP and the speed gets slow for her. Then she comes and asks me 'Are you downloading anything?' and I'm like, 'Yeeees'. Then my wife can say, you know what? High speed for me." (P6)*

> *"(Has no idea about more bandwidth competition among computers - finite amount of network resource - in the home network.) I'm so disappointed. I thought I had an infinite amount of network resource for me. We use such small amount of network. We don't do gaming; we don't watch movies on the Internet. We use it for email, writing documents, and surfing the web. That's it. We don't do any sort of high powered computer use. So we never... That's maybe why my computers never get slower. Because we are not using much capability. So this changes depending on*

what computers or how many applications are cable of using or actually using now? (no idea about network traffic status)" (P7)

"If you are video conferencing and it's getting choppy, it gives you more bandwidth. And I don't know if there is "reduce speed", but nowadays people are downloading stuff all the time and sometimes downloading programs, file sharing program. You might say, 'I want to cap their speed so that they are not hurting me.' The only thing I could see as a problem is I don't see how you can vary this speed from this interface. It looks like it's just like high or nothing, or high or regular instead of like everything or a quarter of the speed, three quartesr of the speed, half of the speed." (P8)

"I could normally go down to the desktop icon and go to the properties from there. This one is more direct and it's giving you information that's generally useful. You can see like maybe these computers do urges, getting slowed down by this computer since it's got all the bandwidth or something." (P12)

"I wouldn't use it for, like, youtube, but maybe the computer is using skype or some other applications that you want to talk to somebody, that will probably be useful." (P13)

"I used to have a roommate who on occasion played a tournament online video game and so we were just trying not to use the Internet during a match because we didn't go to the trouble of configuring priority. So that might be one use. That's the primary use that I've encountered." (P16)

However, user-driven QoS requires social negotiation in some cases, as P11 stated.

> *"I had no idea how to do it. I need to put the high speed on the computer. I want to use this function, but I need to negotiate with my roommate then." (P11)*

Currently, user-driven QoS has not been addressed much by either the network or HCI communities. However, the formative study and the Eden evaluation indicate that user-driven QoS is of interest to users. As the home network becomes more complex with various types of multimedia devices and appliances, I believe that the bandwidth competition among those devices will be of more concern to users.

8.3 Contributions

I conclude my dissertation with a summary of my contributions in this section and future work in the next section.

First, I made the first attempt at adopting direct manipulation based on user interface metaphors for the domain of home network management. The specific contributions are the following:

1. I adopted the spatial concept of a real Home for the model-world interface environment for network management.
2. I adopted real world metaphors that are familiar to users of network management – spatial, link-pipe, badge, and assistant metaphors for management tasks.
3. I made networking devices as visual interactive objects on which users can directly perform tasks by dragging-and-dropping.

4. I made invisible digital controls correspond to management tasks as visual, interactive objects so that users can apply digital controls to the networking devices by dragging-and-dropping.
5. I provided task-oriented GUIs in user-friendly terms while hiding all underlying technical networking minutia.
6. I proved that the new user interface based on direct manipulation was more user friendly than currently available home network management tools.

Second, I proved that my new interaction approach based on direct manipulation improved the usability of Human Network Interaction for unskilled home network users as well as skilled network users. The spicific contributions are the following:

7. I proved that Eden performed better than existing management tools in terms of usability, effectiveness, efficiency, and satisfaction.
8. I found that the graphical GUI of Eden was beneficial to unskilled network user, including novice and intermediate users.

8.4 Future Work

In this section, I discuss future work for Eden and possible post-Eden work. Some of the discussion will be based on the lessons that I learned from the Eden evaluation.

- **Metaphorical changes and UI design with more visual cues and feedback**

Some metaphorical changes to Eden discussed in Section 7.6 warrant more investigation and evaluation. For instance, using the Home abstraction for both physical and logical mappings at the same time caused confusion for some users. I discussed

several alternative approaches to address this problem in Section 7.6, and would like to examine how they work with real users.

I also believe Eden will be able to increase intuitiveness and usability by providing more visual cues and feedback for some of the metaphor breakdowns discussed in Section 7.6.

- **Advanced network troubleshooting heuristics**

From both the formative study and the evaluation study, troubleshooting was a huge concern of the study participants. In particular, users with little technical knowledge had no idea where to go or how to start diagnosing when they confronted networking problems.

HomeNet Doctor provided those users with a more usable troubleshooting user interface. It allowed them to visually explore networking devices and directly pinpoint non-functional devices, as well as to get network diagnosis information for non-functional devices. Expert users also found HomeNet Doctor more usable, compared to traditional command-line tools built-into OS or a router and Network Magic's text-based troubleshooting approach. Therefore, I believe HomeNet Doctor has great potential for usable network troubleshooting.

HomeNet Doctor currently relies on existing simple network diagnosis tools, including "ping" and "netstat." Consequently, it supports simple network diagnosis for network connectivity and slow speed problems.

In the future, I envision HomeNet Doctor as being equipped with advanced troubleshooting mechanics. For instance, it should be able to better diagnose networking slow speed problems based on an in-depth analysis of the network traffic patterns and network usage patterns. It should be able to more accurately diagnose network connectivity problems based on in-depth analysis of the history of network configuration changes.

In addition to passive network diagnosis, HomeNet Doctor should also be able to detect the critical health status of the network and take a predictive or preemptive newtork diagnosis action even before users actually recognize any problem.

- **Advanced network monitoring system**

Eden currently supports an instantaneous snapshot for network monitoring information—displaying the total network and individual devices' bandwidth usage. The study participants found this instantaneous information useful, especially when they need to troubleshoot the network.

In the future, I envision that Eden will provide advanced network monitoring services which are based on the history and network usage patterns of the users. For instance, Eden can provide a more in-depth analysis of Internet usage time and visited websites for parental control. Parental control for Internet and websites was a primary concern to users with children. Therefore, these features will help users make better informed decisions on access control for their children.

The network-layer logging features described here could also be used to provide new application-layer features, beyond the basic Eden management facilities. For instance, say that a user listens to a specific Internet radio channel every morning. The network-layer logging that could be built into a future version of Eden could then remember these patterns, and make them available to applications that might, for example, automatically records the Internet radio channel when the user is away on a trip and allow the user to play it when he/she is back home.

- **Extension of the spatial metaphor to the smart/ubiquitous home network**

Through Eden, I have demonstrated the utility of direct manipulation for the single home network and its basic management tasks, especially by using the spatial metaphor to change the concept of the home network, which is currently unfamiliar and

not easily imaginable to general home users, into a concrete, physical space. The network as a "space" helped users acquire a better understanding of the concept of the home network and effectively communicated the complexity of device configurations as a simple matter of adding devices to or removing them from the space. It also allows users to more effectively control a group of devices throughout the Rooms in the Home.

In the future, I think the spatial concept could be used to manage even more complex home network environments equipped with various types of small networking devices as will be found in smart homes. Smart homes are equipped with various types of networked computing devices that are interconnected to provide intelligent services, and small networking devices are spread all over the home. Providing users with a physical sense of locations and activities of the devices will help them get a more concrete idea about their home networks and allow them to effectively perform management tasks including membership management and small device connection. In addition, such space-based approaches will allow users to more effectively control multiple small devices in a group-based manner. The spatial concept also has the potential to integrate social aspects and family routine patterns. As in Eden, access rights can be associated with a specific place, and the ownership and purpose of a device can be implied by the location of the device.

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